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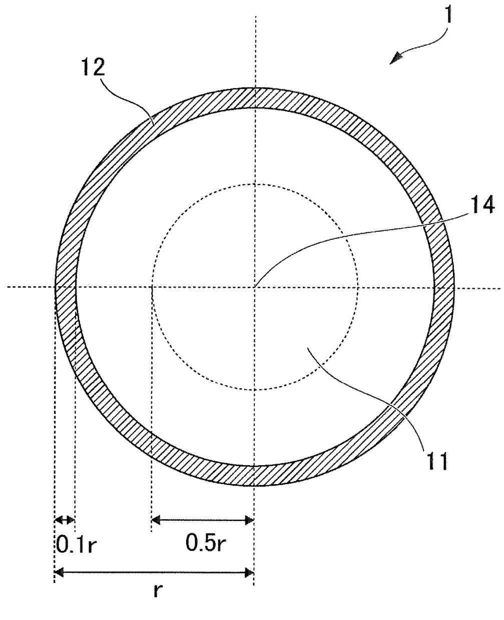
(54) STEEL WIRE MATERIAL AND PRODUCTION METHOD FOR STEEL WIRE MATERIAL

(57) A steel wire rod according to an aspect of the present invention has a chemical composition in a predetermined range, in which a structure in a central part includes 80 area% to 100 area% of pearlite and a total of 0 area% or more and less than 20 area% of proeutectoid ferrite, proeutectoid cementite, martensite, and bainite; an average lamellar spacing of the pearlite in the central part is 50 nm to 100 nm; an average length of lamellar cementite in the central part is 1.9 μm or less; an average pearlite block size in the central part is 15.0 μm to 30.0 μm; a structure in a surface part includes 70 area% to 100 area% of the pearlite; and an average pearlite block size in the surface part is 0.40 times or more and 0.87 times or less the average pearlite block size in the central part.

FIG. 1



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Description

[Technical Field of the Invention]

[0001] The present invention relates to a steel wire rod used as a material for an overhead power transmission line and various ropes, and a manufacturing method thereof.

[Related Art]

[0002] Aluminum conductor steel-reinforced cable (hereinafter, "ACSR") is an electric wire having a configuration in which a zinc-coated steel wire is disposed at the center and hard aluminum wires are concentrically stranded around the steel wire, with each layer having alternating lays. In the related art, the steel wire for ACSR use has been mainly playing a role as a tension member for aluminum wires. As the steel wire for ACSR use, a steel wire obtained by drawing a pearlitic steel and performing zinc coating thereon, an aluminum-clad steel wire obtained by drawing a steel wire rod having an aluminum layer formed as the surface layer to improve corrosion resistance, and the like have been used in the related art.

[0003] From the viewpoint of improving the power transmission efficiency, in order to reduce the specific gravity of the whole electric wire and increase the area of aluminum, an increase in the strength and a reduction in the diameter of the steel core of the steel wire for ACSR use are required.

[0004] For example, as a method for improving the power transmission efficiency of the ACSR, there are reducing the weight of the ACSR, increasing the cross-sectional area of aluminum, reducing the electric resistance of the steel wire, and the like. For example, from the viewpoint of reducing the weight of the ACSR, Patent Document 1 discloses a method of reducing the specific gravity of an ACSR by using carbon fiber as the core wire of the ACSR. In addition, from the viewpoint of reducing the electric resistance of the steel wire, Patent Document 2 discloses a method of improving the electric conductivity of a steel wire by specifying the amounts of C, Si, and Mn of the steel wire to small amounts.

[0005] In addition, in IEC 61232 published by the International Electrotechnical Commission, the torsional performance required for an aluminum-clad steel wire is defined as 20 or more times. Therefore, an increase in ductility in addition to an increase in strength and a reduction in diameter is required for the aluminum-clad steel wire. From the viewpoint of improving the torsional performance, Patent Document 3 discloses a method of refining the pearlite block size and lamellar spacing of a steel wire by adding a small amount of Ni to the steel wire, thereby improving the value of a reduction in area and the strength of the steel wire.

[0006] However, the ACSR obtained by the technique disclosed in Patent Document 1 described above uses expensive carbon fiber as its core wire, so that a higher cost is incurred compared to an ACSR using a steel wire as its core wire. In addition, in the technique disclosed in Patent Document 2, since the amounts of the alloying elements of the steel wire are reduced, it is difficult to secure the strength as the tension member of the steel core of the steel wire. Furthermore, in the technique disclosed in Patent Document 3, N is solid soluted into lamellar ferrite by adding Ni and the electric resistance of the steel wire is increased, and thus, which is not preferable from the viewpoint of reducing the electric resistance.

[0007] Moreover, in general, there is a tendency that the tensile strength of a steel wire rod and the electric resistivity of the steel wire rod have a proportional relationship, so that it is difficult to manufacture a steel wire rod having both high tensile strength and high electric conductivity. Recently, in order to reduce the specific gravity of an electric wire, a steel wire rod having a tensile strength of preferably 1050 MPa or more, and more preferably 1100 MPa or more is required. However, it has been difficult in the related art to impart sufficient electric conductivity to the steel wire rod having such a tensile strength for the above mentioned applications.

[Prior Art Documents]

[Patent Documents]

[0008]

[Patent Document 1] Japanese Unexamined Patent Application, First Publication No. 2001-176333
[Patent Document 2] Japanese Unexamined Patent Application, First Publication No. 2003-226938
[Patent Document 3] PCT International Publication No. WO2012/124679

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0009] The present invention has been made taking the foregoing circumstances into consideration, and an object thereof is to provide a steel wire rod which has a high tensile strength and a relatively low electric resistivity with respect to the tensile strength, and furthermore enables a steel wire having excellent torsional properties to be manufactured, and a manufacturing method thereof. Particularly, an object of the present invention is to provide a steel wire rod having a relatively high electric conductivity (that is, low electric resistivity) with respect to a high tensile strength, and a manufacturing method thereof.

[0010] As described above, in general, there is a tendency that the tensile strength of a steel wire and the electric resistivity of a steel wire rod have a proportional relationship. The inventors investigated the relationship between the tensile strength TS (MPa) and the electric resistivity ρ ($\mu\Omega\cdot$cm) of a steel wire rod in the related art, and as a result, found that the electric resistivity of a steel wire rod for ACSR use in the related art is practically in the following range.

[0011] In a case where the Si content is 0.100 mass% or more, $\rho > 0.0155 \times TS + 1.25$

[0012] In a case where the Si content is less than 0.100 mass%, $\rho > 0.0155 \times TS - 0.95$

[0013] Therefore, in a case where the tensile strength TS and the electric resistivity ρ of the steel wire rod satisfy Formula (1) in a case where the Si content is 0.100 mass% or more, and in a case where Formula (2) is satisfied in a case where the Si content is less than 0.100 mass%, the electric resistivity of the steel wire rod is improved from the level in the related art.

$$\rho \leq 0.0155 \times TS + 1.25 \ldots \text{Formula (1)}$$

$$\rho \leq 0.0155 \times TS - 0.95 \ldots \text{Formula (2)}$$

[0014] In addition, there may be cases where the value obtained by substituting the tensile strength into the right side of Formula (1) or Formula (2) is referred to as an electric resistivity threshold. In the present invention, "a steel wire rod having high electric conductivity" means a steel wire rod having an electric resistivity equal to or less than the electric resistivity threshold obtained based on Formula (1) or Formula (2).

[Means for Solving the Problem]

[0015] The gist of the present invention is as follows.

(1) According to an aspect of the present invention, a steel wire rod includes, as a chemical composition, by unit mass%: C: 0.60% to 1.10%; Si: 0.005% to 0.350%; Mn: 0.10% to 0.90%; Cr: 0.010% to 0.300%; N: 0.0100% or less; P: 0.030% or less; S: 0.030% or less; Al: 0% to 0.070%; Ti: 0% to 0.030%; V: 0% to 0.100%; Nb: 0% to 0.050%; Mo: 0% to 0.20%; B: 0% to 0.0030%; and a remainder including Fe and impurities; in which, when a distance from a circumferential surface to a central axis of the steel wire rod is defined as r in units of mm, a structure in a central part which is a region from the central axis to r × 0.5 includes 80 area% to 100 area% of pearlite and a total of 0 area% or more and less than 20 area% of proeutectoid ferrite, proeutectoid cementite, martensite, and bainite; an average lamellar spacing of the pearlite in the central part is 50 nm to 100 nm; an average length of lamellar cementite in the central part is 1.9 μm or less; an average pearlite block size in the central part is 15.0 μm to 30.0 μm; a structure in a surface part which is a region from the circumferential surface to r × 0.1 includes 70 area% to 100 area% of the pearlite; and an average pearlite block size in the surface part is 0.40 times or more and 0.87 times or less the average pearlite block size in the central part.

(2) The steel wire rod according to (1) may include, as the chemical composition, by unit mass%: Si: 0.100% to 0.350%; in which the average pearlite block size in the surface part may be 17.0 μm or less, and a relationship between a tensile strength TS [MPa] and an electric resistivity ρ [$\mu\Omega\cdot$cm] of the steel wire rod may satisfy Formula (i).

$$\rho \leq 0.0155 \times TS + 1.25 \ldots \text{Formula (i)}$$

(3) The steel wire rod according to (1) may include, as the chemical composition, by unit mass%: Si: 0.005% or more and less than 0.100%; in which the average pearlite block size in the surface part may be 0.80 times or less the average pearlite block size in the central part, and a relationship between a tensile strength TS [MPa] and an

electric resistivity ρ [μΩ·cm] of the steel wire rod may satisfy Formula (ii).

$$\rho \leq 0.0155 \times TS - 0.95 \ldots \text{Formula (ii)}$$

(4) The steel wire rod according to any one of (1) to (3) may include, as the chemical composition, by unit mass%: at least one or more selected from the group consisting of Al: 0.001 % to 0.070%, Ti: 0.002% to 0.030%, V: more than 0% and 0.100% or less, Nb: more than 0% and 0.050% or less, Mo: more than 0% and 0.20% or less, and B: 0.0003% to 0.0030%.

(5) According to another aspect of the present invention, a manufacturing method of a steel wire rod includes: casting a bloom containing, as a chemical composition, by unit mass%, C: 0.60% to 1.10%, Si: 0.005% to 0.350%, Mn: 0.10% to 0.90%, Cr: 0.010% to 0.300%, N: 0.0100% or less, P: 0.030% or less, S: 0.030% or less, Al: 0% to 0.070%, Ti: 0% to 0.030%, V: 0% to 0.100%, Nb: 0% to 0.050%, Mo: 0% to 0.20%, B: 0% to 0.0030%, and a remainder including Fe and impurities; heating the bloom to a heating temperature in a temperature range of 1150°C or higher and 1250°C or lower; retaining a temperature of the bloom at the heating temperature for 600 seconds to 7200 seconds; hot rolling the bloom after the retaining so that a finishing temperature is 950°C or higher and 1050°C or lower to obtain a hot rolled steel; water cooling the hot rolled steel to a temperature range of 780°C or higher and 840°C or lower; winding the hot rolled steel after the water cooling in the temperature range of 780°C or higher and 840°C or lower; patenting the hot rolled steel after the winding by immersing the hot rolled steel in a molten salt at a temperature of 450°C or higher and T1°C or lower defined by Formula (iii) for 20 seconds to 200 seconds, within 9 seconds to 25 seconds after the winding; and tempering the hot rolled steel after the patenting to obtain the steel wire rod by heating the hot rolled steel to a tempering temperature in a temperature range of 540°C to 600°C, retaining the hot rolled steel at the tempering temperature for 30 seconds to 600 seconds, and cooling the hot rolled steel to room temperature,

$$T1\ [°C] = -r'\ [mm] \times 16 + 580 \ldots \text{Formula (iii)}$$

where r' is a distance from a circumferential surface to a central axis of the hot rolled steel in units of mm.

(6) In the manufacturing method of a steel wire rod according to (5), the steel wire rod may include, as the chemical composition, by unit mass%, at least one or more selected from the group consisting of Al: 0.001 % to 0.070%, Ti: 0.002% to 0.030%, V: more than 0% and 0.100% or less, Nb: more than 0% and 0.050% or less, Mo: more than 0% and 0.20% or less, and B: 0.0003% to 0.0030%.

[Effects of the Invention]

[0016] According to the present invention, it is possible to provide a steel wire rod which has a high tensile strength and a relatively low electric resistivity with respect to the tensile strength, and furthermore enables a steel wire having excellent torsional properties to be manufactured, and a manufacturing method thereof.

[Brief Description of the Drawings]

[0017]

FIG. 1 is a C-sectional view of a steel wire rod according to an embodiment.

FIG. 2 is a view showing an L-section of the steel wire rod according to the embodiment, and measurement points of the average length of lamellar cementite in a pearlite structure.

FIG. 3 is a diagram showing the relationship between the ratio (PBS ratio) between the average pearlite block grain size in a surface part and a central part of a steel wire rod having a Si content of less than 0.100%, and the number of torsion of a wire obtained from the steel wire rod.

FIG. 4 is a diagram showing the relationship between the average pearlite block size (surface PBS) in a surface part of a steel wire rod having a Si content of 0.100% to 0.350% and the number of torsion of a wire.

FIG. 5 is a flowchart showing a manufacturing method of the steel wire rod according to the embodiment.

[Embodiments of the Invention]

[0018] A steel wire rod according to an embodiment of the present invention and a manufacturing method thereof will be described below.

[0019] A steel wire rod of this embodiment shown in FIG. 1 has a predetermined chemical composition, and the structure in a central part 11, which is a region from the central axis of the steel wire rod 1 to r × 0.5 and the structure in a surface part 12, which is a region from the circumferential surface of the steel wire rod to r × 0.1 are controlled to predetermined morphologies. Here, r is the distance from the circumferential surface of the steel wire rod 1 to the central axis of the steel wire rod 1.

[0020] First, the chemical composition of the steel wire rod according to this embodiment will be described. The unit of the chemical composition is mass%.

(C: 0.60% to 1.10%)

[0021] C has an effect of increasing the strength of the steel wire rod by increasing the cementite fraction of a pearlite structure in the steel and refining the lamellar spacing of the pearlite structure. In a case where the C content is less than 0.60%, it becomes difficult to obtain an amount of the pearlite structure specified by this embodiment, so that the strength of the steel wire rod is decreased. In order to set the amount of the pearlite structure to be in the specified range, the C content is set to 0.60% or more. The C content is preferably 0.65% or more, and more preferably 0.70% or more. On the other hand, in a case where the C content exceeds 1.10%, the conductivity of the steel wire rod is decreased, and the ductility of the steel wire rod is decreased by forming proeutectoid cementite. Therefore, the upper limit of the C content is set to 1.10%. In order to improve the ductility of the steel wire, it is effective to reduce the amount of the proeutectoid cementite, so that the C content is preferably 1.05% or less, more preferably 1.00% or less, and even more preferably 0.95% or less.

(Si: 0.005% to 0.350%)

[0022] Si is an element that improves the hardenability of the steel wire rod, is an element effective for suppressing the formation of proeutectoid cementite during patenting, and is an element effective for solid solution strengthening and deoxidation of the steel wire rod. However, in a case where the Si content is less than 0.005%, it becomes difficult to control the pearlite structure to a predetermined configuration, and in a case where the C content is large, it becomes difficult to suppress the formation of proeutectoid cementite. Therefore, the lower limit of the Si content is set to 0.005%. On the other hand, Si segregates in the ferrite of the pearlite structure and increases the electric resistivity of the steel wire rod. When Si is contained in an amount exceeding 0.350%, the electric resistivity of the steel wire rod is significantly increased. Therefore, the Si content is defined as 0.005% to 0.350%.

[0023] As the Si content increases, the tensile strength of the steel wire rod is increased, and the conductivity of the steel wire rod is decreased. In a case where a steel wire rod with further increased strength is required, the Si content of the steel wire rod may be set to 0.100% to 0.350%. In this case, as will be described later, it is desirable that the tensile strength TS (MPa) and the electric resistivity ρ (μΩ·cm) of the steel wire rod satisfy Formula (1).

$$\rho \leq 0.0155 \times \mathrm{TS} + 1.25 \ldots \text{Formula (1)}$$

[0024] On the other hand, in a case where a steel wire rod with further increased conductivity is required, the Si content of the steel wire rod may be set 0.005% or more and less than 0.100%. In this case, as will be described later, it is desirable that the tensile strength TS (MPa) and the electric resistivity ρ (μΩ·cm) of the steel wire rod satisfy Formula (2).

$$\rho \leq 0.0155 \times \mathrm{TS} - 0.95 \ldots \text{Formula (2)}$$

[0025] By increasing the Si content, controlling the structure to a predetermined configuration is facilitated, so that the yield is improved. Therefore, the Si content may set to preferably 0.010% or more, and more preferably 0.030% or more. In order to obtain a steel wire rod and a steel wire having further reduced electric resistivity, the Si content may be set to preferably 0.250% or less, more preferably 0.200% or less, and even more preferably 0.150% or less.

(Mn: 0.10% to 0.90%)

[0026] Mn is a deoxidizing element, and is an element that has an action of suppressing red brittleness by fixing S in the steel as MnS and suppresses a decrease in conductivity due to solid solute S. In addition, Mn reduces the area ratio of the proeutectoid ferrite structure of the steel wire rod by improving the hardenability of the steel wire rod during patenting, and has an effect of increasing the strength of the steel wire rod. However, in a case where the Mn content is less than 0.10%, the effect of the above action cannot be sufficiently obtained. Therefore, the lower limit of the Mn content is set to 0.10%. On the other hand, Mn lowers the conductivity of steel. Therefore, the upper limit of the Mn content is set to 0.90%. In addition, in order to sufficiently secure the hardenability of steel and also secure conductivity, the upper limit of the Mn content is set to preferably 0.80% or less, and more preferably 0.60% or less.

(Cr: 0.010% to 0.300% or Less)

[0027] Cr is an element that improves hardenability, and is an element that increases the tensile strength of the steel wire rod by decreasing the lamellar spacing of the pearlite. In order to obtain this effect, it is necessary to set the Cr content to 0.010% or more. The Cr content is more preferably 0.020% or more. On the other hand, in a case where a steel wire rod is manufactured under patenting conditions in which distribution of Cr hardly occurs, Cr sometimes decreases the conductivity. In order to prevent the decrease in conductivity, the upper limit of the Cr content is set to 0.300%. The Cr content is more preferably 0.250% or less.

[0028] Furthermore, in the steel wire rod according to this embodiment, the amounts of N, P, and S are limited as follows. Since N, P, and S are not necessary for the steel wire rod according to this embodiment, the lower limits of the amounts of N, P, and S are 0%.

(N: 0.0100% or Less)

[0029] N decreases the ductility of steel due to strain aging during cold working. In particular, in a case where the N content exceeds 0.0100%, the ductility of the steel wire rod is decreased and the conductivity is also decreased. Therefore, the N content is limited to 0.0100% or less. The N content is preferably 0.0080% or less, and more preferably 0.0050% or less.

(P: 0.030% or Less)

[0030] P contributes to solid solution strengthening of ferrite, but significantly reduces the ductility of the steel wire rod. In particular, in a case where the P content exceeds 0.030%, the deterioration in drawability during drawing of a steel wire rod into a steel wire becomes significant. Therefore, the P content is limited to 0.030% or less. The P content is preferably 0.012% or less.

(S: 0.030% or Less)

[0031] S is an element that causes red brittleness and further reduces the ductility of steel. In a case where the S content exceeds 0.030%, the ductility of the steel wire rod is significantly decreased, so that the S content is limited to 0.030% or less. The S content is preferably 0.010% or less.

[0032] The steel wire rod according to this embodiment may contain one or more elements selected from the group consisting of Al, Ti, V, Nb, Mo, and B, in addition to the above mentioned elements. However, since the steel wire rod according to this embodiment can exhibit excellent properties without containing Al, Ti, V, Nb, Mo, and B, the lower limits of the amounts of Al, Ti, V, Nb, Mo, and B are 0%.

(Al: 0% to 0.070%)

[0033] Al is an element which is a deoxidizing element, and can fix N and refine the austenite grain size by forming nitrides. In order to obtain this effect, the Al content may be set to 0.001 % or more. In addition, in a case where Al is not fixed as a nitride but present as free Al in lamellar ferrite, the conductivity of the steel wire rod is decreased. Therefore, the upper limit of the Al content is set to 0.070%. The Al content is preferably 0.060% or less, and more preferably 0.050% or less.

(Ti: 0% to 0.030%)

[0034] Ti is an element which is a deoxidizing element and can refine the austenite grain size by forming carbonitrides. In order to obtain this effect, the Ti content may be set to 0.002% or more. On the other hand, in a case where the Ti content exceeds 0.030%, there may be cases where coarse nitrides are incorporated during steelmaking, carbides precipitate during the patenting treatment of a hot rolled steel, and the ductility of the steel wire rod is decreased. Therefore, the upper limit of the Ti content is set to 0.030%. The Ti content is preferably less than 0.025%.

(V: 0% to 0.100%)

[0035] V is an element that improves hardenability, and improves the tensile strength of the steel by precipitating as carbonitrides. In order to obtain this effect, the V content may be set to be more than 0%, or 0.002% or more. On the other hand, in a case where the V content is excessive, the time to complete transformation during patenting is increased, and the ductility and toughness of the steel wire rod are decreased due to precipitation of coarse carbonitrides. Therefore, the upper limit of the V content is set to 0.100%. The V content is preferably 0.080% or less.

(Nb: 0% to 0.050%)

[0036] Nb is an element that improves hardenability, and is an element that can refine the austenite grain size by precipitating as carbides. In order to obtain this effect, the Nb content may be set to be more than 0%, or 0.002% or more. On the other hand, in a case where the Nb content exceeds 0.050%, the time to complete transformation during patenting is increased. Therefore, the Nb content is set to 0.050% or less. The Nb content is preferably 0.002% to 0.020%.

(Mo: 0% to 0.20%)

[0037] Mo is an element that improves hardenability and reduces the amount of proeutectoid ferrite. In order to obtain this effect, the Mo content may be set to be more than 0%, or 0.02% or more. However, in a case where the Mo content is excessive, the time to complete transformation during patenting of the steel wire rod is increased. Therefore, the upper limit of the Mo content is set to 0.20%. The Mo content is preferably 0.10% or less.

(B: 0% to 0.0030%)

[0038] B is an element that improves hardenability, and is an element that improves the amount of pearlite by suppressing the formation of proeutectoid ferrite. In order to obtain this effect, the B content may be set to 0.0003% or more. On the other hand, in a case where the B content exceeds 0.0030%, $M_{23}(C,B)_6$ precipitates on the austenite grain boundaries in a supercooled state during patenting of the steel wire rod, so that the ductility of the wire is impaired. Therefore, the B content is preferably set to 0.0003% to 0.0030%. The B content is more preferably set to 0.0020% or less.

[0039] The remainder of the chemical composition of the steel wire rod according to this embodiment contains iron and impurities. The impurities are elements that are incorporated from raw materials or a steel manufacturing process, and mean elements that are acceptable in a range in which the steel wire rod according to this embodiment is not adversely affected.

[0040] Next, the structure of the steel wire rod according to this embodiment will be described. The target value of the tensile strength of the steel wire rod according to this embodiment is preferably 1050 MPa or more, and more preferably 1100 MPa or more. In order to obtain a steel wire rod having such tensile strength, high conductivity, and ductility, the central part 11 and the surface part 12 of the steel wire rod 1 according to this embodiment needs to have the following structures. There is no need to separately control the configuration of the transition region between the central part 11 and the surface part 12 as long as the configurations in the central part 11 and the surface part 12 are appropriately controlled. Therefore, the configuration of the transition region of the steel wire rod according to this embodiment is not particularly limited. The tensile strength of the steel wire rod according to this embodiment is not limited to the above mentioned target value, and may be set depending on the application.

(Structure in Central Part Includes 80 area% to 100 area% of Pearlite and Total of 0 area% or More and Less than 20 area% of Proeutectoid Ferrite, Bainite, Proeutectoid Cementite, Martensite, and the like)

[0041] The structure in the central part includes 80 area% to 100 area% of the pearlite structure, and 0 area% or more and less than 20 area% of a structure other than pearlite, such as proeutectoid ferrite, a bainite structure, proeutectoid cementite, martensite, and the like. When the amount of the pearlite structure in the central part becomes less than 80 area% and the amount of the structure other than pearlite becomes 20 area% or more, sufficient tensile strength is not obtained. In order to further improve the tensile strength, the lower limit of the amount of pearlite in the central part of the steel wire rod according to this embodiment may be set to 82 area%, 85 area%, 87 area%, 90 area%, or 92 area%, and the upper limit of the amount of the structure other than pearlite may be set to 18 area%, 15 area%, 13 area%, 10 area%, or 8 area%. Since the structure in the central part of the steel wire rod according to this embodiment does not require the structure other than pearlite, the upper limit value of the amount of pearlite in the central part of the steel wire rod according to this embodiment is 100 area%, and the lower limit of the amount of the structure other than pearlite is 0 area%. However, in order to improve the yield, the upper limit of the amount of pearlite in the central part of the steel wire rod according to this embodiment may be set to 99 area%, 98 area%, or 97 area%, and the lower limit of the amount of the structure other than pearlite may be set to 1 area%, 2 area%, or 3 area%.

(Structure in Surface Part Includes 70 area% to 100 area% of Pearlite)

[0042] The structure in the surface part includes 70 area% to 100 area% of pearlite. The surface part and the central part of the steel wire rod differ in processing and thermal history in a manufacturing stage and a heat treatment stage of the steel wire rod, and the actual transformation temperature at the surface part is lower than at the central part. Therefore, the amount of pearlite in the surface part of the steel wire rod is typically smaller than the amount of pearlite in the central part of the steel wire rod. However, in a case where the amount of pearlite in the surface part of the steel wire rod is less than 70%, the ductility of the surface part of the steel wire rod becomes insufficient, so that the torsional performance of the steel wire rod is deteriorated. Therefore, the amount of pearlite in the surface part of the steel wire rod according to this embodiment is set to 70 area% or more. The lower limit of the amount of pearlite in the surface part of the steel wire rod may be set to 72 area%, 75 area%, or 80 area%. Since the structure in the surface part of the steel wire rod according to this embodiment does not require a structure other than pearlite, the upper limit of the amount of pearlite in the surface part of the steel wire rod according to this embodiment is 100 area%, and the lower limit of the amount of the structure other than pearlite is 0 area%. However, in order to improve the yield, the upper limit of the amount of pearlite in the surface part of the steel wire rod according to this embodiment may be set to 99 area%, 98 area%, or 97 area%, and the lower limit of the amount of the structure other than pearlite may be set to 1 area%, 2 area%, or 3 area%. As the structure other than pearlite included in the surface part of the steel wire rod, as in the central part of the steel wire rod, proeutectoid ferrite, a bainite structure, proeutectoid cementite, martensite, and the like are exemplified. However, since the surface part of the steel wire rod undergoes large processing deformation, the surface part of the steel wire rod may include a structure of which the kind cannot be identified due to severe deformation. The amount of pearlite in the surface part of the steel wire rod is a value that does not include the amount of the structure of which the kind cannot be identified.

[0043] Pearlite has a lamellar structure having ferrite and cementite alternating in a layered manner. In this embodiment, lamellar ferrite (ferrite constituting pearlite) and lamellar cementite (cementite constituting pearlite) are distinguished from the proeutectoid ferrite and proeutectoid cementite described above.

(Average Lamellar Spacing of Pearlite in Central Part: 50 nm to 100 nm)

[0044] The average lamellar spacing of the pearlite structure in the central part of the steel wire rod according to this embodiment is in a range of 50 nm to 100 nm. In a case where the distribution of alloying elements into the lamellar ferrite is the same, the conductivity is increased as the lamellar spacing is decreased. Therefore, the average lamellar spacing of the pearlite structure in the central part of the steel wire rod is set to 100 nm or less. The upper limit of the average lamellar spacing of the pearlite structure in the central part of the steel wire rod is preferably 98 nm, 95 nm, 93 nm, or 90 nm. On the other hand, in a case of composition and heat treatment conditions under which the average lamellar spacing of the pearlite structure in the central part is less than 50 nm, the amount of the alloying elements is large and it is difficult to distribute the alloying elements. Therefore, the lower limit thereof is set to 50 nm.

(Average Length of Lamellar Cementite in Central Part: 1.9 μm or Less)

[0045] The present inventors found that the average length of the lamellar cementite in the pearlite in the central part of the steel wire rod according to this embodiment is correlated with the conductivity of the steel wire rod, and as the lamellar cementite is divided and thus the average length of the lamellar cementite is decreased, the conductivity of the steel wire rod is increased. In a case where the average length of the lamellar cementite in the central part of the steel wire rod exceeds 1.9 μm, the conductivity of the steel wire rod is not sufficiently improved. Therefore, the average length of the lamellar cementite in the pearlite in the central part of the steel wire rod according to this embodiment is set to 1.9 μm or less. The average length of the lamellar cementite in the pearlite in the central part is preferably 1.8 μm or less, 1.6 μm or less, 1.5 μm or less, 1.4 μm or less, or 1.3 μm or less. In order to set the average length of the lamellar cementite in the central part of the steel wire rod to be 1.9 μm or less by dividing the lamellar cementite, as will be described later, it is necessary to set the average pearlite block grain size in the central part of the steel wire rod to 15 μm or more and to include tempering in the manufacturing method of the steel wire rod.

(Average Pearlite Block Size in Central Part: 15.0 μm to 30.0 μm)

[0046] As described above, the average length of the lamellar cementite in the pearlite in the central part of the steel wire rod according to this embodiment needs to be 1.9 μm or less. In order to obtain a steel wire rod having such lamellar cementite, as will be described later, it is necessary to divide the lamellar cementite by performing tempering on hot rolled steel, which is an intermediate material of the steel wire rod, under a predetermined condition after patenting to form pearlite. The present inventors found that as the average pearlite block size in the central part decreases, the lamellar cementite is less likely to be divided during tempering.

[0047] As understood by the present inventors, in a case where the average pearlite block size in the central part is less than 15.0 μm, it is extremely difficult to set the average length of the lamellar cementite in the pearlite in the central part to be 1.9 μm or less. Therefore, the average pearlite block size in the central part of the steel wire rod according to this embodiment needs to be 15.0 μm or more. The average pearlite block size in the central part of the steel wire rod may be defined as 17.0 μm or more, 18.0 μm or more, or 20.0 μm or more.

[0048] On the other hand, as the average pearlite block size in the central part increases, the ductility of the steel wire rod is decreased. Due to the feature in which only the average pearlite block size in the surface part of the steel wire rod is reduced, which will be described later, the ductility of the steel wire rod can be secured without hindering the division of the lamellar cementite of the steel wire rod. However, in a case where the average pearlite block size in the central part exceeds 30.0 μm, the ductility of the steel wire rod cannot be preferably maintained even if this feature is utilized. Therefore, the average pearlite block size in the central part needs to be 30.0 μm or less. The average pearlite block size in the central part may be defined as 27.0 μm or less, 25.0 μm or less, or 20.0 μm or less.

(Average Pearlite Block Size in Surface part: 0.40 Times or More and 0.87 Times or Less Average Pearlite Block Size in Central Part)

[0049] The structure in the surface part of the steel wire rod affects the ductility of a wire (steel wire) obtained by drawing the steel wire rod, against torsional deformation. By refining the pearlite block size in the surface part of the steel wire rod, the nonuniformity of the structure is suppressed, so that the ductility of the wire obtained by drawing the steel wire rod can be improved. However, as described above, when the pearlite block size of the entire steel wire rod is refined, the division of the lamellar cementite is impeded. Therefore, it is necessary to refine the pearlite blocks in the surface part so as to set the ratio (hereinafter, sometimes abbreviated to "PBS ratio") of the average pearlite block size in the central part to the average pearlite block size in the surface part to be 0.87 or less. Accordingly, it is possible to secure the ductility of the steel wire rod (and the ductility of the wire obtained by drawing the steel wire rod) without impeding the division of the lamellar cementite. The PBS ratio is more preferably set to 0.85 or less. Although the lower limit of the PBS ratio is not particularly limited, it is difficult to set the PBS ratio to be less than 0.40 in consideration of facility capability and the like, so that the lower limit of the PBS ratio may be set to 0.40, 0.50, or 0.60.

[0050] In a steel wire rod having a Si content in a range of 0.005% or more and less than 0.100% (hereinafter, abbreviated to "low Si steel wire rod"), the PBS ratio thereof is preferably 0.80 or less. FIG. 3 is a graph showing the relationship between the PBS ratios of low Si steel wire rods and the number of torsions of wires obtained from these low Si steel wire rods. The present inventors prepared various low Si steel wire rods and measured the PBS ratios of these low Si steel wire rods and the number of torsions of wires obtained from these low Si steel wire rods. As a result, as shown in FIG. 3, it could be seen that as the PBS ratio of the low Si steel wire rod decreases, the number of torsion of the wire is increased, and particularly in a case where the PBS ratio is 0.80 or less, the number of torsion of the wire is significantly increased. When the Si content is less than 0.10%, the pearlite block growth rate becomes faster and the pearlite block size tends to become coarse. Therefore, in comparison to the structure in the central part, the PBS ratio is more suitable as an index indicating the ductility of the structure in the surface layer, than the absolute value of the PBS. Delamination had occurred in a wire obtained from a low Si steel wire rod having a PBS ratio of more than 0.87 during a test.

[0051] Furthermore, in a steel wire rod having a Si content in a range of 0.100% to 0.350% (hereinafter, abbreviated to "high Si steel wire rod"), the average pearlite block size in the surface part of the steel wire rod (surface PBS) is set to preferably 17.0 μm or less, and more preferably 16.0 μm or less. FIG. 4 is a graph showing the relationship between the surface PBSs of high Si steel wire rods and the number of torsions of wires obtained from these steel wire rods. The present inventors prepared various high Si steel wire rods and measured the surface PBSs of these high Si steel wire rods and the number of torsions of wires obtained from these low Si steel wire rods. As a result, as shown in FIG. 4, it could be seen that as the surface PBS of the high Si steel wire rod decreases, the number of torsion of the wire is increased, and particularly in a case where the surface PBS is 17.0 μm or less, the number of torsion of the wire is significantly increased.

[0052] In the steel wire rod according to this embodiment, from the viewpoint of increasing both the strength and conductivity of the steel wire rod as an ACSR, it is preferable that the relationship between the tensile strength TS (MPa) and the electric resistivity ρ (μΩ·cm) of the steel wire rod is defined using Formula (1) for the case of high Si steel wire rods and Formula (2) for low Si steel wire rods.

$$\rho \leq 0.0155 \times \mathrm{TS} + 1.25 \ \ldots \ \text{Formula (1)}$$

$$\rho \leq 0.0155 \times TS - 0.95 \ldots \text{Formula (2)}$$

[0053] A high Si steel wire rod is used for a product which is not strictly restricted in terms of conductivity but requires high tensile strength. A low Si steel wire rod is used for a product which is not strictly restricted in terms of tensile strength but requires high conductivity. In consideration of such a difference in application, it is preferable to define the relationship between the tensile strength and the electric resistivity using different formulas for the high Si steel wire rod and the low Si steel wire rod. The steel wire rod according to this embodiment has the above described features and thus has the tensile strength and electric resistivity satisfying Formula (1) or Formula (2).

[0054] Next, a method of specifying the structure of the steel wire rod according to this embodiment will be described. Hereinafter, a section which is parallel to the longitudinal direction of the steel wire rod and includes the central axis of the steel wire rod is referred to as an L-section, and a section perpendicular to the longitudinal direction of the steel wire rod is referred to as a C-section.

[0055] The average lamellar spacing of the pearlite in the central part 11 is obtained by performing mirror polishing on the L-section of the steel wire rod, performing picral etching thereon, observing the structure with a field emission scanning electron microscopy (FE-SEM), and analyzing the observation result of the structure. The observation of the structure is performed at nine observation points 13 shown in FIG. 2. The observation points 13 in the L-section of the steel wire rod 1 are disposed at the vertices, the center, and the midpoints of the four sides of a rectangular region in which the length of the four sides is the same as the radius r of the steel wire rod 1, two sides are parallel to the longitudinal direction of the steel wire rod, and the center is on a central axis 14 of the steel wire rod 1. At each of the observation points 13, the surface of a section excluding a region, in which 30% or more of the region is point-like cementite having an aspect ratio of 3 or less, is photographed with the FE-SEM at a magnification of 10,000-fold. An electronic image of the photographed region is analyzed to binarize the part of lamellar cementite and is subjected to line segmentation with no thickness. Furthermore, vertical and horizontal lines are drawn for each pixel of the electronic image, and 1/2 of the average value of the lengths of the segments partitioned by the cementite is taken as the average lamellar spacing. The average lamellar spacing is based on the principle described in "Quantitative Microscopy" (Makishima et al., issued on July 30, 1972, by Uchida Rokakuho Publishing Co., Ltd.) p. 115 to p. 117. The average value of the average lamellar spacings in the nine FE-SEM images for the nine observation points 13 can be regarded as the average lamellar spacing in the central part of the steel wire rod.

[0056] Furthermore, the average length of the lamellar cementite in the pearlite structure in the central part 11 is obtained by the following procedure. In the photographed FE-SEM images, the part of the lamellar cementite is binarized in the above described manner, and image analysis is performed thereon, whereby the average length of the lamellar cementite of the pearlite include in the FE-SEM images is calculated. In addition, the average value of the average lamellar cementite lengths in the nine FE-SEM images for the nine observation points 13 can be regarded as the average length of the lamellar cementite in the central part.

[0057] Furthermore, the fraction of the pearlite structure in the central part is obtained by the following procedure. Metallographic structure photographs of the nine observation points 13 with the average lamellar spacing on the cut surface of the steel wire rod are taken at a magnification of 2,000-fold. In each of the photographs, a structure part other than pearlite is marked and enclosed, and the area ratio thereof is measured by image analysis. The difference of the area ratio of the structure part other than pearlite from the whole is the area ratio of pearlite in each of the photographs. The average value of the area ratios of pearlite in the photographs can be regarded as the fraction of the pearlite structure in the central part.

[0058] The fraction of the pearlite structure in the surface part, which is a region from the circumferential surface of the steel wire rod to r × 0.1 is obtained by the following procedure. Metallographic structure photographs centered on a depth of r × 0.05 from the circumferential surface of the steel wire rod are taken at least at four points in the C-section of the steel wire rod (the section perpendicular to the rolled surface) at a magnification of 2,000-fold. It is preferable that the photographed points are uniformly arranged along the outer circumference of the C-section, and for example, in a case where the number of photographed points is four, it is preferable that the photographed points are arranged every 90° along the outer circumference of the C-section. The area ratio of pearlite in the metallographic structure photographs may be obtained by the same method as the method of measuring the fraction of the pearlite structure in the central part. The average value of the area ratios of pearlite in the photographs can be regarded as the fraction of the pearlite structure in the surface part.

[0059] The average pearlite block sizes in the central part and the surface part of the steel wire rod are obtained by an electron back scattered diffraction pattern (EBSD) method. The average pearlite block size in the central part is obtained by measuring, for the nine observation points 13 shown in FIG. 2 in the L-section of the steel wire rod, the average pearlite block size in each visual field with a visual field size of 250 μm × 250 μm using the EBSD method, and thereafter calculating the average value of the average pearlite block sizes of the visual fields. In the measurement, a region surrounded by boundaries with an orientation difference of 9° or more is regarded as one pearlite block grain, and is analyzed using the Johnson-Saltykov measurement method. The average pearlite block size in the surface part is obtained by performing measurement on at least four observation points uniformly arranged along the outer circumference of the C-section in the C-section of the steel wire rod, in the same manner as for the central part. The center of the measurement visual field is set to a depth of r × 0.05 from the circumferential surface of the steel wire rod.

[0060] The electric resistance of the steel wire rod is measured by the following procedure. After removing the scale on the surface layer of the steel wire rod and correcting the steel wire rod into a straight bar, the electric resistance thereof is measured by the four-terminal method. The length and current value to be measured are selected according to the facility within a range in which the temperature of the steel wire rod is not changed by energization, and are measured up to the third digit of the significant digits.

[0061] Next, a manufacturing method of the steel wire rod according to this embodiment will be described. As shown in FIG. 5, the manufacturing method of the steel wire rod of this embodiment includes: S1 of casting a bloom; S2 of heating the bloom; S3 of retaining the temperature of the bloom; S4 of hot rolling the bloom after the retaining to obtain a hot rolled steel; S5 of water cooling the hot rolled steel; S6 of winding the hot rolled steel after the water cooling; S7 of patenting the hot rolled steel after the winding; and S8 of tempering the hot rolled steel after the patenting to obtain a steel wire rod. The manufacturing conditions are described in detail below.

(Casting S1)

[0062] In the manufacturing method of the steel wire rod according to this embodiment, first, steel is melted, and thereafter, a bloom having the chemical composition of the steel wire rod according to this embodiment is manufactured by continuous casting or the like. A billet may also be obtained by blooming the bloom before the hot rolling described later.

(Heating S2: Heating Temperature 1150°C or Higher and 1250°C or Lower)

(Retaining S3: Retention Time 600 Seconds to 7200 Seconds at the Above Heating Temperature)

[0063] The bloom is heated to a heating temperature at which the average temperature of the cross section is in a range of 1150°C to 1250°C before hot rolling, and is then retained at the heating temperature for 600 seconds or longer. In addition, the maximum temperature of the bloom in the heating S2 is referred to as the heating temperature. In a case where heating and retaining are not performed under such conditions, carbonitrides contained in the bloom are insufficiently solutionized, and the average pearlite block size in the central part is outside of the defined range described above. As described above, when the average pearlite block size in the central part is not in the defined range, the division of the lamellar cementite does not proceed. Therefore, in a case where heating and retaining are not performed under such conditions, the average cementite length of the lamellar cementite in the central part also falls outside the above described range, and the conductivity of the steel wire rod is impaired. The retention time is preferably 7200 seconds or shorter from the viewpoint of suppressing decarburization.

(Hot Rolling S4: Finishing Temperature 950°C or Higher and 1050°C or Lower)

[0064] The billet obtained by cooling the bloom once after the rolling and performing heating and retaining thereon is hot rolled into a hot rolled steel. In the hot rolling, the finishing temperature needs to be 950°C to 1050°C. In a case where the finishing temperature is inappropriate, the average pearlite block size in the central part falls outside the defined range. The reason is that when finishing temperature is higher than 1050°C, austenite grains after the hot rolling are coarsened, and thus pearlite is insufficiently formed in the subsequent cooling, whereby the ductility of the surface part is not obtained. On the other hand, the reason is that when the finishing temperature of lower than 950°C, it is difficult for the ratio between the pearlite block sizes in the surface part and the central part to be in the defined range.

(Water Cooling S5: Cooling Stop Temperature 780°C or Higher and 840°C or Lower)

(Winding S6: Winding Temperature 780°C or Higher and 840°C or Lower)

(Patenting S7: Time 9 Seconds to 25 Seconds from End of Winding to Start of Immersion, Molten Salt Temperature 450°C or Higher and T1°C or Lower, and Immersion Time 20 Seconds to 200 Seconds)

[0065] Next, the hot rolled steel after finish rolling is water cooled and wound. The water cooling stop temperature and the winding temperature are set to be in a range of 780°C to 840°C. Next, the wound hot rolled steel is patented by being immersed for 20 seconds or longer in a molten salt at a temperature of 450°C or higher and T1°C or lower, within 9 seconds to 25 seconds after the winding. T1 is a value defined by Formula (3) described below. The symbol " r' " included in Formula (3) represents the radius of the hot rolled steel (that is, the radius of the hot rolled steel) in units of mm. The water cooling, winding, and patenting are the most important for controlling the configuration of the pearlite of the steel wire rod. The immersion time in the molten salt is preferably 200 seconds or shorter from the viewpoint of productivity.

$$T1\ [°C] = -r'\ [mm] \times 16 + 580 \ldots \text{Formula (3)}$$

[0066] In a case where the water cooling stop temperature, the winding temperature, and the time from the completion of the winding to the start of the immersion are outside the above described ranges, the average pearlite block size in the surface part of the steel wire rod does not become 0.87 times or less the average pearlite block size in the central part. The reason is that the austenite grain size in the surface part becomes coarse and the pearlite block size also becomes coarse. The water cooling is started immediately after the completion of the hot rolling. Therefore, the water cooling start temperature becomes substantially the same as the finishing temperature described above. It is presumed that even in a case where the water cooling start temperature is lower than 950°C, there is concern that the configuration of the pearlite may not be appropriately controlled.

[0067] In a case where the molten salt temperature is outside the above described range, the amount of the pearlite in the central part of the steel wire rod becomes less than 80 area%, or the average lamellar spacing of the pearlite in the central part of the steel wire rod exceeds 100 nm. The reason is that, for example, in a case where the molten salt temperature is lower than 450°C, the formation of the bainite structure becomes dominant and the fraction of the pearlite structure is decreased. On the other hand, the reason is that, when the molten salt temperature is the temperature T1 or higher, the lamellar spacing is increased and exceeds 100 nm. In addition, in a case where the immersion time is outside the above range, the subsequent processes are performed while pearlitic transformation is not completed, so that the pearlite fraction and the lamellar spacing cannot be controlled.

(Tempering S8: Tempering Temperature 540°C to 600°C, and Tempering Time 30 Seconds to 600 Seconds)

[0068] The patented hot rolled steel is heated to a tempering temperature in a temperature range of 540°C or higher, retained at this tempering temperature for 30 seconds or longer, and then tempered by being cooled to room temperature.

[0069] From the viewpoint of productivity, the tempering time is preferably 600 seconds or shorter. When the tempering temperature is too high, the strength of the steel wire rod is insufficient due to excessive tempering, so that the tempering temperature is set to 600°C or lower. The tempering temperature is the maximum heating temperature in tempering S8, and the tempering time is the time during which the temperature of the hot rolled steel is retained at the tempering temperature.

[0070] By the tempering under the above described conditions, the lamellar cementite in the central part is divided, and a steel wire rod in which the average cementite length of the lamellar cementite in the central part is 1.9 μm or less is obtained. In a case where at least one of the tempering temperature and the tempering time is insufficient, the division of the lamellar cementite does not proceed sufficiently, and the average cementite length of the lamellar cementite in the central part of the steel wire rod exceeds 1.9 μm, so that the conductivity of the steel wire rod is impaired. In a case where the tempering temperature is too high, the strength is decreased.

[0071] The steel wire rod according to this embodiment has the features in which the central part contains 80 area% to 100 area% of pearlite, the average lamellar spacing of the pearlite in the central part is 50 nm to 100 nm, and the average cementite length of lamellar cementite in the central part is 1.9 μm or less, and thus has high tensile strength and conductivity. Such high tensile strength and conductivity obtained by the above features are maintained even after drawing of the steel wire rod, so that a steel wire obtained by drawing the steel wire rod according to this embodiment also has high tensile strength and conductivity. Furthermore, the steel wire rod according to this embodiment has the features in which the average pearlite block size in the surface part is 0.87 times or less the average pearlite block size in the central part, so that the ductility of the surface part is good. Therefore, the steel wire obtained by drawing the steel wire rod according to this embodiment has excellent torsional properties. That is, with the steel wire rod according to this embodiment, a steel wire excellent in all of tensile strength, conductivity, and torsional properties is obtained.

[Examples]

[0072] Next, examples of the present invention will be described. The conditions in the examples are condition examples adopted for confirming the feasibility and effects of the present invention, and the present invention is not limited to the condition examples. The present invention can adopt various conditions without departing from the gist of the present invention as long as the object of the present invention is achieved.

[0073] Steels having chemical compositions shown in Tables 1 and 2 were cast to obtain blooms of 300 mm × 500 mm. In Tables 1 and 2, values that are equal to or less than levels that are typically regarded as impurities are indicated by the symbol "-". These blooms were bloomed into billets having a 122 mm square cross section.

These billets are heated to heating temperatures shown in Tables 3 and 4 and retained at the heating temperature for a predetermined time. The retention time at the heating temperatures was between 900 seconds to 1200 seconds. After the heating and temperature retention, hot rolling was performed on the billets at finishing temperatures shown in Tables 3 and 4, thereby forming hot rolled steels having wire diameters (diameters) shown in Tables 3 and 4. The hot rolled steels were water cooled to winding temperatures shown in Tables 3 and 4 and wound. Thereafter, a patenting treatment was performed by immersing the hot rolled steels in a salt bath having salt temperatures shown in Tables 3 and 4, whereby pearlitic transformation was completed, within 9 seconds to 25 seconds after the winding. The immersion time of the hot rolled steels in the salt bath was set to 30 seconds. Thereafter, tempering was performed on the hot rolled steels to retain the temperature at tempering temperatures shown in Tables 3 and 4 for a tempering time shown in Tables 3 and 4 and thereafter cool the hot rolled steels to room temperature, whereby steel wire rods were obtained.

[0074] The structures of the obtained steel wire rods are shown in Tables 5 and 6.

[0075] The amount of pearlite contained in the central part of the steel wire rod (the fraction of the pearlite structure in the central part) was obtained by taking structure photographs of nine observation points shown in FIG. 2 in the L-section of the steel wire rod using the FE-SEM, specifying a non-pearlite region included in each structure photograph, obtaining the area ratio of the non-pearlite region of each structure photograph through image analysis, calculating the area ratio of pearlite of each structure photograph based on the area ratio of the non-pearlite region, and averaging the area ratios of pearlite of the structure photographs.

[0076] The amount of pearlite contained in the surface part of the steel wire rod (the fraction of the pearlite structure in the surface part) was obtained by taking structure photographs of four observation points uniformly arranged along the outer circumference of the C-section in the C-section of the steel wire rod and centered on a depth of r × 0.05 from the circumferential surface of the steel wire rod, using the FE-SEM, specifying a non-pearlite region included in each structure photograph, obtaining the area ratio of the non-pearlite region of each structure photograph through image analysis, calculating the area ratio of pearlite of each structure photograph based on the area ratio of the non-pearlite region, and averaging the area ratios of pearlite of the structure photographs.

[0077] The average pearlite block size (central PBS) in the central part of the steel wire rod was obtained by measuring, for the nine observation points 13 shown in FIG. 2 in the L-section of the steel wire rod, the average pearlite block size of each visual field with a visual field size of 250 μm × 250 μm using the EBSD method, and thereafter calculating the average value of the average pearlite block sizes of the visual fields. In the measurement, a region surrounded by boundaries with an orientation difference of 9° or more was regarded as one pearlite block grain, and was analyzed using the Johnson-Saltykov measurement method.

[0078] The average pearlite block size (surface PBS) in the surface part of the steel wire rod was obtained by performing measurement on at least four observation points uniformly arranged along the outer circumference of the C-section in the C-section of the steel wire rod, in the same manner as for the central part. The center of the measurement visual field was set to a depth of r × 0.05 from the circumferential surface of the steel wire rod.

[0079] The ratio (surface / central PBS ratio) between the average pearlite block size in the surface part of the steel wire rod and the average pearlite block size in the central part of the steel wire rod was obtained by dividing the surface PBS by the central PBS described above.

[0080] For the steel wire rod in which the amount of pearlite deviated from the defined range of the present invention by 5% or more, the measurement of the average pearlite block size was omitted. Therefore, the surface PBS, and/or central PBS, and the PBS ratio of the steel wire rod in which the amount of pearlite was outside the defined ranges of the present invention, are indicated by diagonal lines.

[0081] The average lamellar spacing of the pearlite in the central part of the steel wire rod (average lamellar spacing) was obtained by taking structure photographs of the nine observation points shown in FIG. 2 in the L-section of the steel wire rod using the FE-SEM, obtaining the average lamellar spacing of the pearlite included in each structure photograph through the image analysis described above, and further averaging the average lamellar spacings of the structure photographs.

[0082] The average length of the lamellar cementite in the central part of the steel wire rod (average cementite length) was obtained by taking structure photographs of the nine observation points shown in FIG. 2 in the L-section of the steel wire rod using the FE-SEM, obtaining the average length of the lamellar cementite of the pearlite included in each structure photograph through the image analysis described above, and further averaging the average lengths of the lamellar cementite of the structure photographs.

[0083] Tables 7 and 8 show the obtained steel wire rods, and mechanical properties electrical properties of wires obtained by performing dry drawing with a true strain of $\varepsilon = 2.2$ on the steel wire rods.

[0084] The tensile strength TS of the steel wire rod was obtained by a tension test. For each steel wire rod, three tension test pieces having a length of 350 mm were prepared, the tension test was conducted on each tension test piece at room temperature at a tension rate of 10 mm/min, and the average of the tensile strengths of the three tension test pieces was taken as the tensile strength of the steel wire rod. In this example, it was determined that a steel wire rod having a tensile strength of 1050 MPa or more has sufficient tensile strength.

[0085] The electric resistivity ρ of the steel wire rod was obtained by taking a test piece having a grade length of 60 mm from the steel wire rod, and measuring the electric resistivity of the test piece at room temperature according to the four-terminal method. A steel wire rod in which the electric resistivity was equal to or lower than the electric resistivity threshold defined by Formula (1) or Formula (2) was determined to have relatively low electric resistivity with respect to the tensile strength and sufficient electric conductivity. Formula (1) is applied to high Si steel wire rods, and Formula (2) is applied to low Si steel wire rods. For reference, Tables 7 and 8 show which one of Formula (1) and Formula (2) is the mathematical formula (threshold calculation formula) applied to each steel wire rod.

[0086] Furthermore, as described above, dry drawing with a true strain of $\varepsilon = 2.2$ was performed on the steel wire rod to obtain a wire, and the wire was evaluated. As for the drawing conditions, the average reduction of area of each pass was set to 17%. A torsion test with a gauge length of 100 times the wire diameter and a torsion speed of 20 rpm was conducted on the obtained wire three times, and the average value (number of torsion) of the number of times until fracture and the presence or absence of longitudinal cracking (delamination) were checked. The number of times was counted in units of 0.5 times. A steel wire rod which is the material of a wire in which the number of torsion was 24.5 or more and delamination had not occurred in the torsion test was determined to be a steel wire rod from which a wire having excellent torsional performance was obtained.

[Table 1]

Steel	Classification	Chemical composition (mass%) remainder: Fe and impurities												
		C	Si	Mn	Cr	N	P	S	Al	Ti	V	Nb	Mo	B
1	Example	0.60	0.200	0.30	0.023	0.0035	0.015	0.007	0.033	-	-	-	-	-
2		0.66	0.040	0.44	0.050	0.0027	0.013	0.011	0.025	0.015	-	-	-	-
3		0.70	0.070	0.32	0.110	0.0030	0.011	0.009	0.035	-	-	-	-	-
4		0.71	0.020	0.18	0.240	0.0032	0.008	0.008	-	-	-	-	-	-
5		0.71	0.150	0.45	0.011	0.0025	0.015	0.010	-	0.012	-	-	-	-
6		0.72	0.200	0.73	0.025	0.0040	0.009	0.005	-	-	-	-	-	0.0015
7		0.72	0.050	0.25	0.150	0.0020	0.021	0.023	-	-	-	-	-	-
8		0.72	0.005	0.45	0.120	0.0025	0.011	0.009	0.041	-	-	-	-	-
9		0.73	0.100	0.15	0.020	0.0038	0.016	0.012	-	-	-	-	-	-
10		0.73	0.080	0.59	0.055	0.0048	0.010	0.010	0.032	-	-	-	-	-
11		0.74	0.150	0.31	0.018	0.0035	0.009	0.019	0.038	-	-	-	-	-
12		0.75	0.150	0.41	0.087	0.0028	0.020	0.010	-	0.015	-	-	-	-
13		0.76	0.080	0.32	0.100	0.0026	0.014	0.004	-	0.012	-	-	-	-
14		0.76	0.006	0.11	0.190	0.0033	0.017	0.007	0.035	-	-	-	-	-
15		0.77	0.250	0.35	0.200	0.0039	0.011	0.010	-	0.019	-	-	-	-
16		0.78	0.090	0.45	0.110	0.0029	0.013	0.008	0.058	-	-	-	-	-
17		0.79	0.110	0.15	0.290	0.0044	0.012	0.013	-	-	-	-	-	-
18		0.81	0.008	0.88	0.080	0.0038	0.009	0.004	0.049	-	-	-	-	-
19		0.82	0.040	0.30	0.023	0.0025	0.008	0.007	0.004	-	-	-	-	-
20		0.82	0.080	0.29	0.025	0.0040	0.011	0.009	-	-	-	-	0.05	-
21		0.82	0.090	0.21	0.240	0.0037	0.009	0.004	0.030	-	-	-	-	-
22		0.82	0.200	0.72	0.032	0.0027	0.009	0.008	0.065	-	-	-	-	-
23		0.82	0.210	0.42	0.015	0.0028	0.012	0.008	-	-	-	0.019	-	-
24		0.82	0.250	0.30	0.028	0.0026	0.008	0.007	0.004	-	-	-	-	-

(continued)

Steel	Classification	Chemical composition (mass%) remainder: Fe and impurities												
		C	Si	Mn	Cr	N	P	S	Al	Ti	V	Nb	Mo	B
25		0.83	0.190	0.72	0.100	0.0049	0.009	0.008	0.035	-	0.020	-	-	-
26		0.85	0.220	0.72	0.032	0.0042	0.019	0.018	0.029	-	-	-	-	-
27		0.88	0.050	0.78	0.050	0.0030	0.006	0.004	-	-	0.090	-	-	-
28		0.90	0.090	0.46	0.130	0.0025	0.013	0.009	0.068	0.002	0.008	0.009	0.02	0.0002
29		0.90	0.010	0.30	0.150	0.0032	0.010	0.005	0.020	0.005	0.070	0.003	0.09	0.0003
30		0.92	0.150	0.32	0.090	0.0028	0.012	0.007	0.002	0.008	0.030	0.011	0.03	0.0029

The symbol "-" indicates values that are equal to or less than levels that are regarded as impurities.

[Table 2]

Steel	Classification	Chemical composition (mass%) remainder: Fe and impurities												
		C	Si	Mn	Cr	N	P	S	Al	Ti	V	Nb	Mo	B
31	Example	0.93	0.060	0.35	0.080	0.0040	0.006	0.006	0.001	0.016	0.020	0.048	0.07	0.0008
32		0.94	0.180	0.38	0.210	0.0035	0.015	0.011	0.038	0.029	0.004	0.005	0.05	0.0005
33		0.95	0.160	0.35	0.260	0.0033	0.011	0.010	0.045	0.011	0.030	0.006	0.19	0.0020
34		0.97	0.150	0.20	0.250	0.0036	0.009	0.005	0.030	-	0.050	-	-	-
35		0.98	0.030	0.30	0.050	0.0033	0.014	0.010	0.003	0.015	0.020	0.004	0.03	0.0007
36		1.01	0.050	0.28	0.033	0.0032	0.011	0.006	0.060	0.011	0.060	0.010	0.04	0.0010
37		1.04	0.110	0.32	0.025	0.0034	0.010	0.007	0.040	-	-	-	-	-
38		1.04	0.050	0.33	0.028	0.0028	0.013	0.009	0.039	-	-	-	-	-
39		1.09	0.150	0.31	0.100	0.0033	0.012	0.010	-	-	-	-	-	-
40		0.90	0.120	0.31	0.012	0.0025	0.011	0.005	0.010	0.003	-	-	-	-
41	Comparative Example	0.57	0.230	0.75	0.050	0.0045	0.010	0.005	0.032	-	-	-	-	-
42		0.71	0.004	0.45	0.100	0.0033	0.008	0.006	0.035	-	-	-	-	-
43		0.71	0.020	0.18	0.240	0.0032	0.008	0.008	-	-	-	-	-	-
44		0.77	0.050	0.32	0.320	0.0042	0.011	0.004	0.033	-	-	-	-	-
45		0.77	0.160	0.31	0.110	0.0110	0.015	0.009	0.032	-	-	-	-	-
46		0.81	0.200	1.02	0.110	0.0040	0.009	0.008	0.042	-	-	-	-	-
47		0.81	0.360	0.42	0.110	0.0022	0.010	0.007	-	0.010	-	-	-	-
48		0.82	0.090	0.21	0.240	0.0037	0.009	0.004	0.030	-	-	-	-	-
49		0.82	0.090	0.07	0.150	0.0030	0.011	0.004	0.033	-	-	-	-	-
50		0.82	0.200	0.72	0.032	0.0027	0.009	0.008	0.065	-	-	-	-	-
51		0.82	0.160	0.21	0.250	0.0036	0.010	0.005	0.029	0.035	-	-	-	-
52		0.82	1.050	0.30	0.030	0.0024	0.008	0.006	0.003	-	-	-	-	-
53		0.85	0.220	0.72	0.032	0.0042	0.019	0.018	0.029	-	-	-	-	-
54		0.90	0.090	0.46	0.130	0.0025	0.013	0.009	0.068	-	-	-	0.02	-

(continued)

Steel	Classification	Chemical composition (mass%) remainder: Fe and impurities												
		C	Si	Mn	Cr	N	P	S	Al	Ti	V	Nb	Mo	B
55		0.90	0.010	0.30	0.150	0.0032	0.010	0.005	0.020	0.005	0.003	0.003	0.09	0.0003
56		0.90	0.010	0.30	0.150	0.0032	0.010	0.005	0.020	0.005	0.003	0.003	0.09	0.0003
57		0.94	0.180	0.38	0.210	0.0035	0.015	0.011	0.038	0.029	0.004	0.005	0.05	0.0005
58		1.15	0.250	0.33	0.021	0.0035	0.010	0.006	0.042	-	-	-	-	-
59		0.82	0.310	0.40	0.150	0.0035	0.010	0.008	-	0.010	-	-	-	-
60		0.90	0.120	0.31	0.012	0.0025	0.011	0.005	0.010	0.003	-	-	-	-
61		0.90	0.120	0.31	0.012	0.0025	0.011	0.005	0.010	0.003	-	-	-	-

The symbol "-" indicates values that are equal to or less than levels that are regarded as impurities.
Underlined values are outside the ranges of the present invention.

[Table 3]

Test No.	Classification	Manufacturing conditions						
		Heating temperature (°C)	Finishing temperature (°C)	Wire diameter (mm)	Winding temperature (°C)	Salt temperature (°C)	Tempering temperature (°C)	Tempering time (sec)
1	Example	1173	1015	5.5	832	480	550	30
2		1226	997	5.5	814	480	600	30
3		1191	1028	9.0	815	480	550	50
4		1174	964	9.0	792	500	600	50
5		1175	987	5.5	801	500	550	30
6		1228	975	5.5	829	500	550	30
7		1163	977	7.0	837	480	550	30
8		1191	981	7.0	836	500	550	30
9		1177	1001	7.0	809	480	550	30
10		1204	1006	5.5	823	500	550	30
11		1208	1002	5.5	826	500	550	30
12		1170	978	7.0	837	500	550	30
13		1228	984	7.0	810	500	550	30
14		1228	970	7.0	798	480	580	30
15		1193	1019	7.0	823	500	580	50
16		1224	966	7.0	806	480	550	50
17		1226	967	9.0	816	480	550	50
18		1182	1029	9.0	798	500	550	50
19		1219	962	7.0	837	500	550	50
20		1206	994	12.0	826	480	550	50
21		1207	1018	5.5	810	500	550	50
22		1162	970	5.5	828	520	580	50
23		1216	1040	7.0	839	520	550	50

(continued)

Test No.	Classification	Manufacturing conditions						
		Heating temperature (°C)	Finishing temperature (°C)	Wire diameter (mm)	Winding temperature (°C)	Salt temperature (°C)	Tempering temperature (°C)	Tempering time (sec)
24		1205	1016	7.0	828	520	550	50
25		1187	1008	7.0	792	520	550	30
26		1217	998	7.0	839	520	550	30
27		1218	1016	12.0	802	480	550	50
28		1229	974	7.0	810	500	550	300
29		1230	994	7.0	791	500	550	300
30		1199	1022	9.0	815	500	550	50

[Table 4]

Test No.	Classification	Manufacturing conditions						
		Heating temperature (°C)	Finishing temperature (°C)	Wire diameter (mm)	Winding temperature (°C)	Salt temperature (°C)	Tempering temperature (°C)	Tempering time (sec)
31	Example	1194	992	9.0	800	500	550	50
32		1185	1031	5.5	790	500	550	30
33		1217	1023	5.5	834	500	550	30
34		1178	1038	9.0	819	500	550	50
35		1193	965	9.0	796	500	550	50
36		1208	985	7.0	820	500	550	50
37		1196	1014	7.0	791	500	550	50
38		1215	973	7.0	822	500	550	50
39		1228	1034	7.0	819	500	550	50
40		1162	955	7.0	835	500	550	30
41	Comparative Example	1174	1028	7.0	792	500	550	30
42		1195	983	7.0	796	500	550	30
43		1199	1037	12.0	792	500	550	50
44		1193	1032	7.0	827	500	550	30
45		1219	965	7.0	814	500	550	30
46		1202	985	7.0	811	500	550	30
47		1194	979	7.0	801	500	550	50
48		1115	952	7.0	825	500	550	50
49		1163	974	7.0	838	500	550	50
50		1182	1007	7.0	809	440	550	50
51		1208	969	7.0	824	500	580	50
52		1188	971	7.0	835	500	550	30
53		1176	1012	7.0	830	500	500	30

(continued)

Test No.	Classification	Manufacturing conditions						
		Heating temperature (°C)	Finishing temperature (°C)	Wire diameter (mm)	Winding temperature (°C)	Salt temperature (°C)	Tempering temperature (°C)	Tempering time (sec)
54		1152	902	7.0	797	500	550	50
55		1211	985	7.0	750	480	550	50
56		1230	1072	7.0	838	500	550	300
57		1230	1040	7.0	820	500	500	10
58		1175	1026	7.0	836	500	550	30
59		1100	970	7.0	820	520	550	30
60		1268	1000	7.0	821	520	550	30
61		1150	960	7.0	895	500	550	30

Underlined values are outside the ranges of the present invention.

[Table 5]

Test No.	Classification	Structure of wire rod						
		Fraction of pearlite structure in central part (%)	Fraction of pearlite structure in surface part (%)	Surface PBS (μm)	Central PBS (μm)	Surface/ central PBS ratio	Average lamellar spacing (nm)	Average cementite length (μm)
1	Example	81	72	17.0	20.0	0.85	100	1.1
2		91	80	18.0	25.0	0.72	96	1.1
3		92	75	19.0	25.0	0.76	99	1.0
4		93	82	16.5	20.0	0.83	97	1.0
5		91	85	16.0	20.5	0.78	99	1.2
6		94	88	15.0	20.0	0.75	79	1.8
7		92	90	18.5	23.0	0.80	98	1.0
8		95	89	17.0	22.0	0.77	98	1.1
9		88	75	16.5	26.0	0.63	100	1.9
10		95	90	18.0	24.0	0.75	87	1.4
11		91	88	16.0	19.5	0.82	98	1.0
12		93	90	15.0	20.0	0.75	98	1.2
13		94	88	18.0	25.0	0.72	97	1.0
14		93	90	20.0	27.0	0.74	95	0.8
15		94	85	14.0	17.0	0.82	90	1.5
16		96	89	15.0	17.5	0.86	93	1.2
17		95	90	15.5	22.0	0.70	80	1.1
18		97	95	14.0	20.0	0.70	81	1.8
19		96	91	15.0	25.0	0.60	96	0.9
20		96	90	16.0	21.0	0.76	98	0.9
21		96	92	15.5	20.0	0.78	97	1.2
22		97	94	14.5	17.5	0.83	84	1.8
23		96	93	16.5	19.5	0.85	98	1.2
24		95	93	13.5	18.0	0.75	90	1.1
25		97	94	14.5	18.0	0.81	80	1.9
26		95	90	15.0	18.5	0.81	81	1.8
27		97	89	17.5	20.5	0.85	86	1.6
28		98	93	15.5	19.5	0.79	87	1.3
29		98	94	16.0	20.5	0.78	89	1.0
30		99	96	15.5	18.5	0.84	82	1.1

[Table 6]

Test No.	Classification	Structure of wire rod						
		Fraction of pearlite structure in central part (%)	Fraction of pearlite structure in surface part (%)	Surface PBS (μm)	Central PBS (μm)	Surface / central PBS ratio	Average lamellar spacing (nm)	Average cementite length (μm)
31	Example	97	93	19.0	23.0	0.83	90	1.0
32		97	94	17.0	20.0	0.85	85	1.4
33		96	90	16.0	19.0	0.84	85	1.4
34		99	93	16.0	21.0	0.76	93	1.2
35		99	96	18.0	24.5	0.73	87	0.9
36		98	90	17.5	22.0	0.80	83	0.9
37		98	92	17.5	21.0	0.83	81	1.0
38		98	91	18.0	23.5	0.77	80	0.9
39		99	91	15.5	19.0	0.82	79	1.1
40		97	93	16.0	20.0	0.80	93	1.5
41	Comparative Example	75	65				107	2.0
42		94	90	18.5	22.5	0.82	112	1.1
43		93	87	16.5	24.5	0.67	117	1.0
44		96	90	14.5	17.0	0.85	99	1.3
45		93	86	15.5	19.5	0.79	102	1.1
46		97	94	15.0	17.5	0.86	82	1.8
47		95	93	14.5	17.0	0.85	100	1.7
48		96	94	15.5	17.0	0.91	113	2.3
49		96	92	16.5	25.5	0.65	135	3.1
50		62	35				88	0.5
51		96	90	18.0	23.5	0.77	94	1.2
52		78	69	13.0	17.5	0.74	71	1.5
53		98	95	15.0	19.0	0.79	86	2.0
54		99	96	16.5	18.5	0.89	93	1.3
55		99	82	17.5	19.0	0.92	87	1.0
56		86	65		19.5		99	0.8
57		97	93	16.5	21.0	0.79	96	2.0
58		90	90	15.0	19.5	0.77	77	1.2
59		95	90	14.5	19.0	0.76	105	2.1
60		99	95	20.5	23.0	0.89	95	1.4
61		98	95	19.0	21.5	0.88	92	1.2

Underlined values are outside the ranges of the present invention.
In a case where the amount of pearlite deviated from the defined range of the present invention by 5% or more, PBS was not measured, and a diagonal line was drawn.

[Table 7]

Test No.	Classification	Properties of wire rod					Properties of wire	
		Tensile strength TS (MPa)	Electric resistivity ρ (μΩ·cm)	Threshold calculation formula	Electric resistivity threshold (μΩ·cm)	Electric resistivity evaluation	Number of torsion (times)	Delamination
1	Example	1072	17.3	(1)	17.9	GOOD	30.5	Absent
2		1120	16.1	(2)	16.4	GOOD	33.0	Absent
3		1131	16.6	(2)	16.6	GOOD	25.5	Absent
4		1102	15.4	(2)	16.1	GOOD	28.0	Absent
5		1149	17.9	(1)	19.1	GOOD	27.5	Absent
6		1270	20.3	(1)	20.9	GOOD	32.5	Absent
7		1164	16.0	(2)	17.1	GOOD	25.0	Absent
8		1155	16.5	(2)	17.0	GOOD	29.0	Absent
9		1159	15.5	(1)	19.2	GOOD	29.5	Absent
10		1226	18.0	(2)	18.1	GOOD	31.0	Absent
11		1173	17.2	(1)	19.4	GOOD	28.5	Absent
12		1185	18.3	(1)	19.6	GOOD	30.5	Absent
13		1177	16.8	(2)	17.3	GOOD	28.5	Absent
14		1168	14.8	(2)	17.2	GOOD	27.5	Absent
15		1259	20.1	(1)	20.8	GOOD	31.0	Absent
16		1235	17.9	(2)	18.2	GOOD	27.0	Absent
17		1190	17.4	(1)	19.7	GOOD	29.0	Absent
18		1319	19.2	(2)	19.5	GOOD	26.5	Absent
19		1249	15.9	(2)	18.4	GOOD	32.0	Absent
20		1217	16.5	(2)	17.9	GOOD	26.5	Absent
21		1249	17.5	(2)	18.4	GOOD	30.0	Absent
22		1323	20.7	(1)	21.8	GOOD	30.0	Absent
23		1252	19.3	(1)	20.7	GOOD	28.5	Absent

(continued)

Test No.	Classification	Properties of wire rod					Properties of wire	
		Tensile strength TS (MPa)	Electric resistivity ρ (μΩ·cm)	Threshold calculation formula	Electric resistivity threshold (μΩ·cm)	Electric resistivity evaluation	Number of torsion (times)	Delamination
24		1236	19.1	(1)	20.4	GOOD	31.5	Absent
25		1357	21.2	(1)	22.3	GOOD	29.5	Absent
26		1366	21.4	(1)	22.4	GOOD	28.5	Absent
27		1347	19.5	(2)	19.9	GOOD	26.0	Absent
28		1360	18.7	(2)	20.1	GOOD	28.0	Absent
29		1338	16.7	(2)	19.8	GOOD	26.5	Absent
30		1347	18.7	(1)	22.1	GOOD	30.0	Absent

[Table 8]

Test No.	Classification	Properties of wire rod					Properties of wire	
		Tensile strength TS (MPa)	Electric resistivity ρ (μΩ·cm)	Threshold calculation formula	Electric resistivity threshold (μΩ·cm)	Electric resistivity evaluation	Number of torsion (times)	Delamination
31	Example	1355	17.4	(2)	20.1	GOOD	27.5	Absent
32		1406	20.4	(1)	23.0	GOOD	26.0	Absent
33		1412	20.3	(1)	23.1	GOOD	26.5	Absent
34		1381	19.2	(1)	22.7	GOOD	30.5	Absent
35		1407	16.7	(2)	20.9	GOOD	27.0	Absent
36		1454	16.9	(2)	21.6	GOOD	25.5	Absent
37		1496	18.3	(1)	24.4	GOOD	26.5	Absent
38		1497	17.3	(2)	22.3	GOOD	24.5	Absent
39		1546	19.7	(1)	25.2	GOOD	28.0	Absent
40		1348	17.3	(1)	22.1	GOOD	30.5	Absent
41	Comparative Example	1020	20.3	(1)	17.1	BAD	33.5	Absent
42		1085	16.3	(2)	15.9	BAD	24.0	Present
43		1057	15.8	(2)	15.4	BAD	31.0	Absent
44		1191	17.8	(2)	17.5	BAD	21.0	Present
45		1194	18.0	(1)	19.7	GOOD	21.5	Present
46		1329	22.8	(1)	21.8	BAD	28.0	Absent
47		1249	21.9	(1)	20.6	BAD	27.5	Absent
48		1171	17.4	(2)	17.2	BAD	28.5	Absent
49		1080	16.0	(2)	15.8	BAD	28.0	Absent
50		1184	20.9	(1)	19.6	BAD	20.5	Present
51		1266	18.5	(1)	20.9	GOOD	18.5	Present
52		1244	30.9	(1)	20.5	BAD	22.0	Present
53		1328	21.9	(1)	21.8	BAD	30.5	Absent

(continued)

Test No.	Classification	Properties of wire rod					Properties of wire	
		Tensile strength TS (MPa)	Electric resistivity ρ (μΩ·cm)	Threshold calculation formula	Electric resistivity threshold (μΩ·cm)	Electric resistivity evaluation	Number of torsion (times)	Delamination
54		1328	18.8	(2)	19.6	GOOD	23.5	Present
55		1349	16.6	(2)	20.0	GOOD	18.7	Present
56		1252	16.6	(2)	18.5	GOOD	5.0	Present
57		1290	21.3	(1)	21.2	BAD	27.5	Absent
58		1616	21.3	(1)	26.3	GOOD	16.5	Present
59		1288	21.5	(1)	21.2	BAD	27.0	Absent
60		1312	17.1	(1)	21.6	GOOD	19.5	Present
61		1330	17.5	(1)	21.9	GOOD	14.5	Present

[0087] In Tables 1 to 6, values outside the range of the present invention were underlined. In a case of Test Nos. 41 to 61 deviated from the conditions defined in the present invention, at least one of the properties described above did not reach the target value. Contrary to this, in Test Nos. 1 to 40 satisfying the conditions defined in the present invention, all the properties described above reached the target values.

[Brief Description of the Reference Symbols]

[0088]

1: steel wire rod
11: central part
12: surface part
13: observation point
14: central axis

Claims

1. A steel wire rod comprising, as a chemical composition, by unit mass%:

   C: 0.60% to 1.10%;
   Si: 0.005% to 0.350%;
   Mn: 0.10% to 0.90%;
   Cr: 0.010% to 0.300%;
   N: 0.0100% or less;
   P: 0.030% or less;
   S: 0.030% or less;
   Al: 0% to 0.070%;
   Ti: 0% to 0.030%;
   V: 0% to 0.100%;
   Nb: 0% to 0.050%;
   Mo: 0% to 0.20%;
   B: 0% to 0.0030%; and
   a remainder including Fe and impurities,
   wherein, when a distance from a circumferential surface to a central axis of the steel wire rod is defined as r in units of mm, a structure in a central part which is a region from the central axis to r × 0.5 includes 80 area% to 100 area% of pearlite and a total of 0 area% or more and less than 20 area% of proeutectoid ferrite, proeutectoid cementite, martensite, and bainite,
   an average lamellar spacing of the pearlite in the central part is 50 nm to 100 nm,
   an average length of lamellar cementite in the central part is 1.9 μm or less,
   an average pearlite block size in the central part is 15.0 μm to 30.0 μm,
   a structure in a surface part which is a region from the circumferential surface to r × 0.1 includes 70 area% to 100 area% of the pearlite, and
   an average pearlite block size in the surface part is 0.40 times or more and 0.87 times or less the average pearlite block size in the central part.

2. The steel wire rod according to claim 1 comprising, as the chemical composition, by unit mass%:

   Si: 0.100% to 0.350%, wherein
   the average pearlite block size in the surface part is 17.0 μm or less, and
   a relationship between a tensile strength TS [MPa] and an electric resistivity ρ [μΩ·cm] of the steel wire rod satisfies Formula (1).

$$\rho \leq 0.0155 \times \mathrm{TS} + 1.25 \ldots \text{Formula (1)}$$

3. The steel wire rod according to claim 1 comprising, as the chemical composition, by unit mass%:

Si: 0.005% or more and less than 0.100%, wherein
the average pearlite block size in the surface part is 0.80 times or less the average pearlite block size in the central part, and
a relationship between a tensile strength TS [MPa] and an electric resistivity ρ [μΩ·cm] of the steel wire rod satisfies Formula (2).

$$\rho \leq 0.0155 \times \mathrm{TS} - 0.95 \ldots \text{Formula (2)}$$

4. The steel wire rod according to any one of claims 1 to 3 comprising, as the chemical composition, by unit mass%:

at least one or more selected from the group consisting of
Al: 0.001% to 0.070%,
Ti: 0.002% to 0.030%,
V: more than 0% and 0.100% or less,
Nb: more than 0% and 0.050% or less,
Mo: more than 0% and 0.20% or less, and
B: 0.0003% to 0.0030%.

5. A manufacturing method of a steel wire rod, comprising:

casting a bloom including, as a chemical composition, by unit mass%,

C: 0.60% to 1.10%,
Si: 0.005% to 0.350%,
Mn: 0.10% to 0.90%,
Cr: 0.010% to 0.300%,
N: 0.0100% or less,
P: 0.030% or less,
S: 0.030% or less,
Al: 0% to 0.070%,
Ti: 0% to 0.030%,
V: 0% to 0.100%,
Nb: 0% to 0.050%,
Mo: 0% to 0.20%,
B: 0% to 0.0030%, and
a remainder including Fe and impurities;

heating the bloom to a heating temperature in a temperature range of 1150°C or higher and 1250°C or lower;
retaining a temperature of the bloom at the heating temperature for 600 seconds to 7200 seconds;
hot rolling the bloom after the retaining so that a finishing temperature is 950°C or higher and 1050°C or lower to obtain a hot rolled steel;
water cooling the hot rolled steel to a temperature range of 780°C or higher and 840°C or lower;
winding the hot rolled steel after the water cooling in the temperature range of 780°C or higher and 840°C or lower;
patenting the hot rolled steel after the winding by immersing the hot rolled steel in a molten salt at a temperature of 450°C or higher and T1°C or lower defined by Formula (3) for 20 seconds to 200 seconds, within 9 seconds to 25 seconds after the winding; and
tempering the hot rolled steel after the patenting to obtain the steel wire rod by heating the hot rolled steel to a tempering temperature in a temperature range of 540°C to 600°C, retaining the hot rolled steel at the tempering temperature for 30 seconds to 600 seconds, and cooling the hot rolled steel to room temperature,

$$\mathrm{T1}\ [^\circ\mathrm{C}] = -r'\ [\mathrm{mm}] \times 16 + 580 \ldots \text{Formula (3)}$$

where r' is a distance from a circumferential surface to a central axis of the hot rolled steel in units of mm.

6. The manufacturing method of a steel wire rod according to claim 5,
wherein the steel wire rod includes, as the chemical composition, by unit mass%, at least one or more selected from

the group consisting of

Al: 0.001 % to 0.070%,
Ti: 0.002% to 0.030%,
V: more than 0% and 0.100% or less,
Nb: more than 0% and 0.050% or less,
Mo: more than 0% and 0.20% or less, and
B: 0.0003% to 0.0030%.

FIG. 1

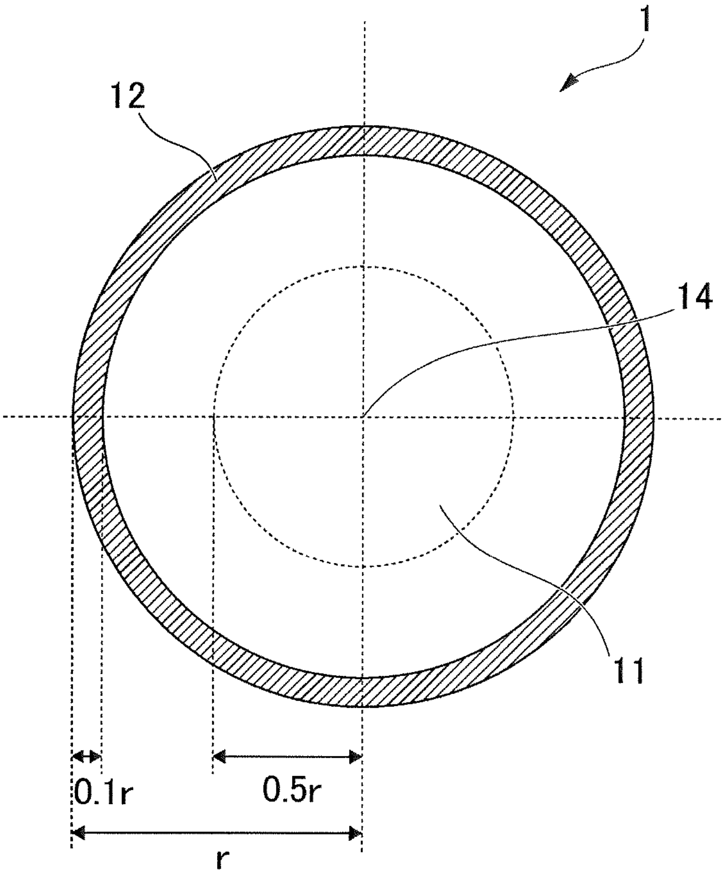


FIG. 2

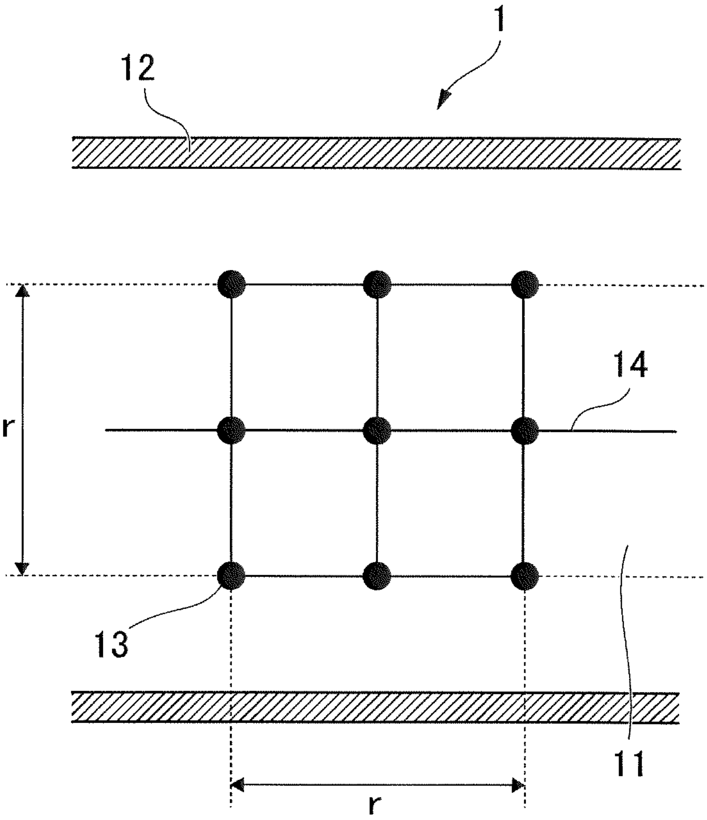


FIG. 3

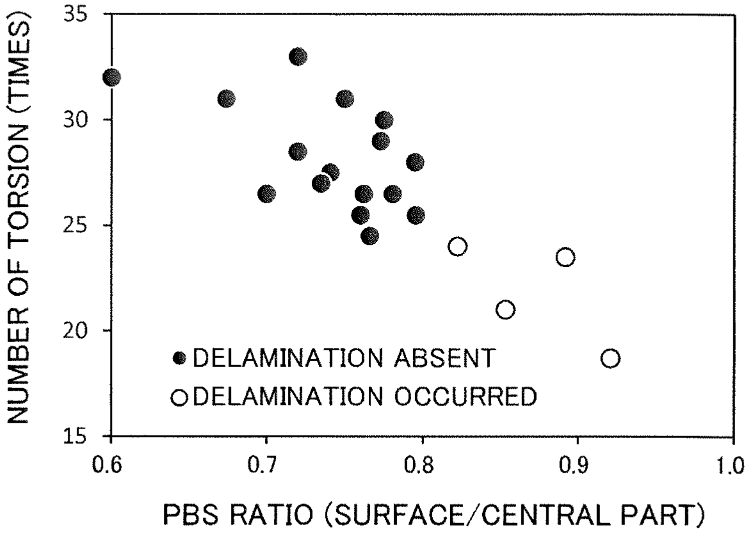

35
30
25
20
15
NUMBER OF TORSION (TIMES)
● DELAMINATION ABSENT
○ DELAMINATION OCCURRED
0.6
0.7
0.8
0.9
1.0
PBS RATIO (SURFACE/CENTRAL PART)

FIG. 4

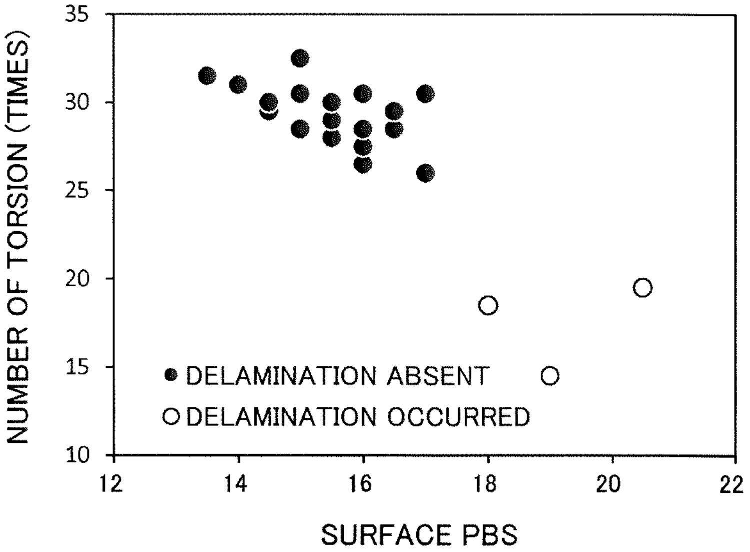
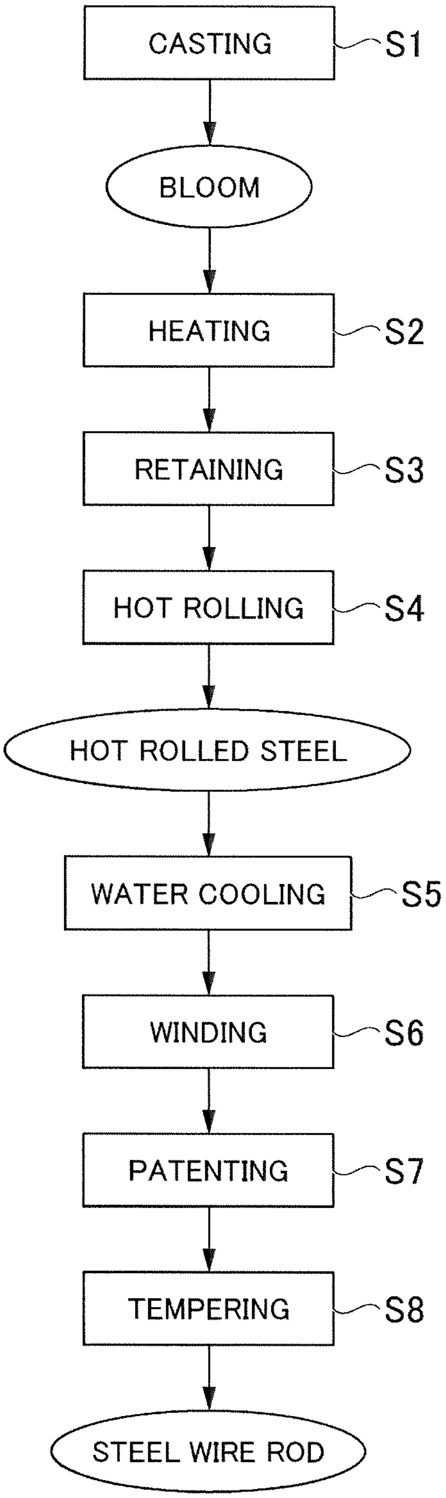

35
30
25
20
15
10
NUMBER OF TORSION (TIMES)
● DELAMINATION ABSENT
○ DELAMINATION OCCURRED
12
14
16
18
20
22
SURFACE PBS

FIG. 5


CASTING
S1
BLOOM
HEATING
S2
RETAINING
S3
HOT ROLLING
S4
HOT ROLLED STEEL
WATER COOLING
S5
WINDING
S6
PATENTING
S7
TEMPERING
S8
STEEL WIRE ROD

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2016/080060

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21D8/06*(2006.01)i, *C21D9/52*(2006.01)i, *C22C38/32*(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00-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.
A	WO 2012/124679 A1 (Nippon Steel Corp.), 20 September 2012 (20.09.2012), & JP 5224009 B2 & US 2014/0000767 A1 & EP 2687619 A1 & CN 102959115 A & KR 10-2013-0034029 A	1-6
A	WO 2011/055746 A1 (Nippon Steel Corp.), 12 May 2011 (12.05.2011), & JP 5154694 B2 & US 2011/0229718 A1 & CN 102216482 A & KR 10-2011-0082042 A	1-6
A	JP 2008-7856 A (Nippon Steel Corp.), 17 January 2008 (17.01.2008), (Family: none)	1-6

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"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
04 January 2017 (04.01.17)

Date of mailing of the international search report
17 January 2017 (17.01.17)

Name and mailing address of the ISA/
Japan Patent Office
3-4-3,Kasumigaseki,Chiyoda-ku,
Tokyo 100-8915,Japan

Authorized officer

Telephone No.

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

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2016/080060

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 11-229088 A (Nippon Steel Corp.), 24 August 1999 (24.08.1999), (Family: none)	1-6
A	JP 8-295991 A (Nippon Steel Corp.), 12 November 1996 (12.11.1996), (Family: none)	1-6
A	KR 10-2011-0047383 A (POSCO), 09 May 2011 (09.05.2011), (Family: none)	1-6

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- JP 2003226938 A **[0008]**
- WO 2012124679 A **[0008]**

Non-patent literature cited in the description

- **MAKISHIMA et al.** Quantitative Microscopy. Uchida Rokakuho Publishing Co., Ltd, 30 July 1972, 115-117 **[0055]**