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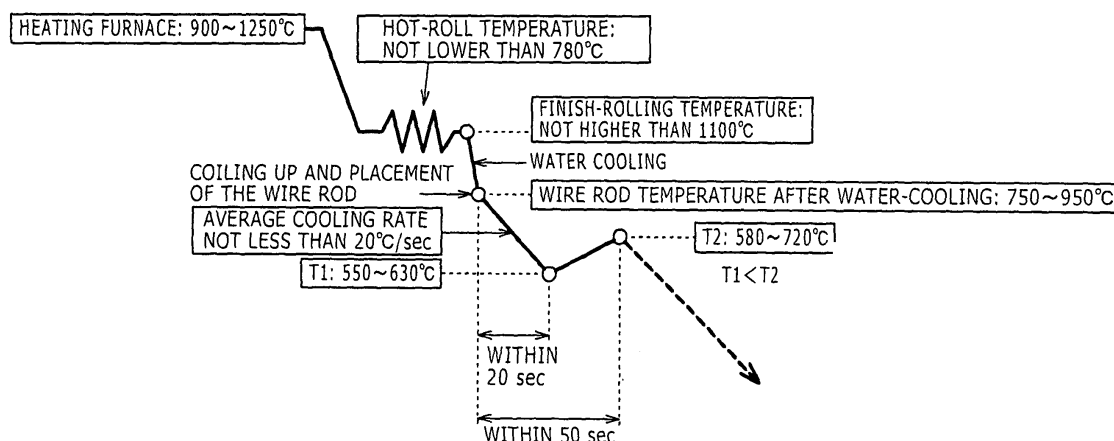
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(54) **Wire rod excellent in wire-drawing workability and method for producing same**

(57) Disclosed are a wire rod and a method therefor. The wire rod is excellent in wire-drawing workability, insusceptible to wire break in spite of an increase in wire-drawing rate, and reduction of area, and capable of extending a die life by suppressing die wear. The wire rod is made of steel containing C: 0.6 to 1.1 %, Si: 0.1 to 2.0%, Mn: 0.1 to 1 %, P: not more than 0.20 %, S: not

more than 0.20 %, N: not more than 0.006 %, Al : not more than 0.03 %, and O: not more than 0.003 %, the balance including Fe, and unavoidable impurities. Further, the wire rod comprises a pearlite structure wherein an area ratio of a second-phase ferrite is not more than 11.0 %, and a pearlite lamellar spacing is not less than 120 μm .

FIG. 3



Description**BACKGROUND OF THE INVENTION**

[0001] The invention relates to a wire rod excellent in wire-drawing workability, out of which a drawn wire product, such as a steel cord, beading wire, PC steel wire, spring steel, can be efficiently produced with high productivity, and a method for producing the same.

[0002] In most cases of producing a drawn wire product, such as a steel cord, a drawing process is applied to a wire rod serving as material for the wire product in order to make adjustment in size and quality (physical properties), and therefore, it is extremely useful from the viewpoint of enhancement in productivity, and so forth to improve wire-drawing workability of the wire rod. In this connection, if improvement on wire drawing workability is implemented, this will not only improve productivity, due to an increase in drawing rate and a decrease in the number of drawing passes, but also provide many benefits such as reduction in wear and tear of draw dies.

[0003] Accordingly, in a pertinent technical field, researches on enhancement in the wire drawing workability of the wire rod have been under way. For example, in Japanese Unexamined Patent Application Publication (JP-A) No. 91912 / 2004, there has been disclosed a technology for improving the wire-drawing workability by focusing attention on size of a pearlite block, a quantity of pro-eutectoid cementite formed, an average thickness of cementite, Cr concentration in cementite, and so forth, and by optimizing them.

[0004] Further, in JP-A-295930 / 1996, there has been disclosed that the wire-drawing workability is improved by controlling an area ratio of upper bainite formation, and growth size of intergranular bainite. In JP-A-130258/1987, there has been disclosed a technology for improving resistance to wire break, and a die life by controlling an amount of total oxygen, and nonviscous inclusion composition, in steel.

[0005] However, a rise in wire-drawing rate, and an increase in reduction of area per one pass cause degradation in ductility of a drawn wire product, and deterioration in die life. Accordingly, in order to further enhance productivity in the pertinent technical field, there is still a demand for a wire rod excellent in the wire-drawing workability, capable of achieving excellent resistance to wire-break, and enhancement of the die life even in harsh wire-drawing conditions of high wire-drawing rate, and large reduction of area.

SUMMARY OF THE INVENTION

[0006] Under circumstances described as above, the invention has been developed, and it is therefore an object of the invention to provide a wire rod excellent in wire-drawing workability, insusceptible to wire break in spite of an increase in wire-drawing rate, and reduction of area, and capable of extending a die life by suppressing die wear, and a method for producing the same.

[0007] According to one aspect of the invention, a wire rod that has succeeded in achieving the object is made of steel containing C: 0.6 to 1.1 % (mass %, applicable to all components referred to hereunder), Si: 0.1 to 2.0%, Mn: 0.1 to 1 %, P: not more than 0.020 % (0 % exclusive), S: not more than 0.020 % (0 % exclusive), N: not more than 0.006 % (0 % exclusive), Al: not more than 0.03 % (0 % exclusive), and O : not more than 0.003 % (0 % exclusive), the balance including Fe, and unavoidable impurities, and further, the wire rod comprises a pearlite structure wherein an area ratio of a second-phase ferrite is not more than 11.0 %, and a pearlite lamellar spacing is not less than 120 μm .

[0008] The wire rod according to the aspect of the invention may contain not more than 1.5 % Cr for higher strength, and may further contain not more than 1 % Cu, and / or not more than 1 % Ni, for suppression of decarburization.

[0009] The wire rod according to the aspect of the invention preferably further contains at least one element selected from the group consisting of not more than 0.30 % V, not more than 0.1 % Ti, not more than 0.10 % Nb, not more than 0.5 % Mo, and not more than 0.1 % Zr from the viewpoint of refinement of the metal microstructure, and suppression of transformation into ferrite.

[0010] The wire rod according to the aspect of the invention may further contain at least one element selected from the group consisting of not more than 5 ppm Mg, not more than 5 ppm Ca, and not more than 1.5 ppm REM in order to soften oxides and enhance the wire drawing workability. Still further, the wire rod according to the invention may contain not more than 15 ppm B in order to enhance hardenability.

[0011] In accordance with another aspect of the invention, there is provided a method for producing a wire rod, comprising the steps of heating a steel product meeting requirements for chemical components, as described hereinbefore, to a temperature in a range of 900 to 1250°C, hot rolling the steel product at a temperature not lower than 780°C, and finish-rolling the same at a temperature not higher than 1100°C to be thereby formed into a wire rod, water-cooling the wire rod to a temperature range of 750 to 950°C before coiling the same up to be placed on conveying equipment, cooling the wire rod at an average cooling rate of not less than 20°C / sec within 20 sec from the coiling of the wire rod to thereby drop temperature of the wire rod to a minimum value point (T1) in a temperature range of 550 to 630°C, and subsequently heating the wire rod to thereby raise the temperature of the wire rod up to a maximum value point (T2) in

a temperature range of 580 to 720°C, higher in temperature than T1, within 50 sec from the coiling of the wire rod.

[0012] The inventor, et al. have found out to their surprise that a wire rod excellent in wire-drawing workability, insusceptible to wire break, and capable of extending a die life by suppressing die wear, can be obtained by specifying the respective contents of C, Si, Mn, P, S, N, Al, and O while controlling the area ratio of the second-phase ferrite and the pearlite lamellar spacing. With the use of the wire rod described, it will become possible to increase a wire-drawing rate, and reduction of area, thereby enabling productivity to be further enhanced.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Embodiments of the present invention will be described in detail based on the following figures, wherein:

Fig. 1 is a SEM photograph of a location at D / 4 on the cross-sectional face of a wire rod according to an embodiment of the invention (D: diameter of the wire rod); (the SEM photograph used for explaining about the structure of a second-phase ferrite),

Fig. 2 is another SEM photograph of a location at D / 4 on the cross-sectional face of the wire rod (D: diameter of the wire rod); (the SEM photograph used for explaining about a method of finding a pearlite lamellar spacing), and Fig. 3 is a schematic representation showing a treatment pattern adopted in a method for producing the wire rod according to the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0014] A wire rod according to the invention has features lying in requirements for chemical components thereof, and requirements for a metal microstructure thereof (an area ratio of a second-phase ferrite, and a pearlite lamellar spacing). Accordingly, the chemical components of the wire rod (a steel product) are first described hereinafter.

C: 0.6 to 1.1 % (mass %, applicable to all components referred to hereunder)

[0015] Carbon is an element intensely affecting strength of the wire rod, and in order to secure strength required of a steel cord, beading wire, PC steel wire, and so forth, as targets for which the invention has been developed, addition of not less than 0.6 % C is required. On the other hand, if carbon content is excessive, there occurs degradation in ductility, so that an upper limit of the carbon content is set to 1.1 %. The carbon content is preferably in a range of 0.8 to 1.0 %.

Si: 0.1 to 2.0%

[0016] For the purpose of deoxidation, in particular, Si is added to a wire rod to be subjected to intense drawing, and addition of not less than 0.1 % Si is required. Further, because Si also contributes to enhancement in strength of the wire rod due to solid solution hardening, an addition amount thereof is increased as necessary. However, an excessive increase in the strength due to excessive addition of Si will cause deterioration in wire-drawing workability. Furthermore, the excessive addition of Si will cause promotion of decarburization, to which attention should be given. For those reasons, with the invention, an upper limit of silicon content is set to 2.0 % to prevent deterioration in wire-drawing workability, and promotion of decarburization. The silicon content is preferably in a range of 0.15 to 1.8 %.

Mn: 0.1 to 1 %

[0017] Addition of not less than 0.1 % Mn is required for the purpose of deoxidization, and locking a deleterious element S in the form of MnS to thereby render S harmless. Further, Mn also acts so as to stabilize carbide in steel. However, because excessive Mn content will cause occurrence of segregation, and supercooled structures, thereby causing deterioration in wire drawing workability, an upper limit of Mn content is set to 1 %. The Mn content is more preferably in a range of 0.15 to 0.9 %.

P: not more than 0.020 % (0 % exclusive)

[0018] P is an element deleterious to wire drawing workability, in particular, and because excessive P content causes degradation in tenacity and ductility of a wire rod, an upper limit of P content is set to 0.020 %. The P content is more preferably not more than 0.015 %, and further preferably, not more than 0.010 %.

S: not more than 0.020 % (0 % exclusive)

[0019] S as well is an element deleterious to wire drawing workability, in particular. If Mn is contained, S can be locked in the form of MnS, as described above, however, excessive S content causes an increase in amount as well as size of MnS, thereby resulting in degradation of ductility, an upper limit of S content is set to 0.020 %. The S content is more preferably not more than 0.015 %, further preferably, not more than 0.010 %.

N: not more than 0.006 % (0 % exclusive)

[0020] N is an element contributing to an increase in strength due to age hardening. A preferable lower limit of N content is 0.001 %. However, because the N content causes degradation in ductility, an upper limit thereof is set to 0.006 %. The upper limit is preferably not more than 0.004 %, more preferably, not more than 0.003 %.

Al: not more than 0.03 % (0 % exclusive)

[0021] Al is an element effective as a deoxidizer, and further, is combined with N to form AlN, which contributes to refinement of a metal microstructure. A preferable lower limit of Al content is 0.0003 %. However, if the Al content is excessive, this will cause coarse oxides to be formed, thereby resulting in deterioration of wire drawing workability, and an upper limit thereof is therefore set to 0.03 %. The upper limit thereof is preferably not more than 0.01 %, more preferably not more than 0.005 %.

O: not more than 0.003 % (0 % exclusive)

[0022] If oxygen content in steel is high, the coarse oxides are prone to be easily formed, thereby resulting in deterioration of wire drawing workability, and an upper limit of the oxygen content is therefore set to 0.003 %. The upper limit thereof is preferably not more than 0.002 %, more preferably not more than 0.0015 %.

[0023] With the wire rod according to the invention, the chemical components described as above represent basic components, and the balance includes in effect Fe, and unavoidable impurities, however, the wire rod may contain the following elements if needs be.

Cr: not more than 1.5 %

[0024] Cr is an element effective for rendering the wire rod higher in strength, and a preferable lower limit of Cr content is 0.01 %. However, since excessive addition of Cr causes supercooled structures prone to be formed to thereby cause deterioration in wire drawing workability, an upper limit of the Cr content is set to 1.5 %. The upper limit thereof is preferably not more than 1.0 %.

Cu: not more than 1 %

[0025] Cu is an element acting so as to enhance corrosion resistance besides acting so as to suppress decarburization in a surface layer, and therefore, Cu can be added as necessary. A preferable lower limit of Cu content is 0.01 %. However, because excessive addition of Cu will not only render the wire rod susceptible to cracking upon hot working, but also adversely affect wire drawing workability due to formation of supercooled structures, an upper limit of the Cu content is set to 1 %. The upper limit thereof is preferably not more than 0.8 %.

Ni: not more than 1 %

[0026] Ni is an element effective for suppressing decarburization in the surface layer, and enhancement in corrosion resistance, as with the case of Cu, and therefore, Ni can be added as necessary. A preferable lower limit of Ni content is 0.01 %. However, because excessive addition of Ni will cause deterioration in the wire drawing workability due to formation of supercooled structures, an upper limit of the Ni content is set to 1 %. The upper limit thereof is preferably not more than 0.8 %.

V: not more than 0.30 %

[0027] V is an element contributing to refinement of the metal microstructure by forming carbide in carbon steel. Further, because V in solid solution state will enhance hardenability, and suppress transformation into ferrite, V can be added as necessary. A preferable lower limit of V content is 0.0010 %. However, because excessive addition of V will

cause deterioration in the wire drawing workability due to formation of supercooled structures, an upper limit of the V content is set to 0.3 %. The upper limit thereof is preferably not more than 0.25 %.

Ti: not more than 0.1 %

[0028] Ti is an element contributing to the refinement of the metal microstructure, and the suppression of transformation into ferrite as with the case of V, and Ti can therefore be added as necessary. A preferable lower limit of Ti content is 0.0010 %. However, because excessive addition of Ti will cause deterioration in wire drawing workability, an upper limit of the Ti content is set to 0.1 %. The upper limit thereof is preferably not more than 0.08 %.

Nb: not more than 0.10 %

[0029] Nb is an element contributing to the refinement of the metal microstructure, and the suppression of transformation into ferrite as with the case of V, and Nb can therefore be added as necessary. A preferable lower limit of Nb content is 0.020 %. However, because excessive addition of Nb will cause deterioration in wire drawing workability, an upper limit of the Nb content is set to 0.10 %. The upper limit thereof is preferably not more than 0.08 %.

Mo: not more than 0.5 %

[0030] Mo is an element contributing to the refinement of the metal microstructure, and the suppression of transformation into ferrite as with the case of V, and Mo can therefore be added as necessary. A preferable lower limit of Mo content is 0.05 %. However, because excessive addition of Mo will cause deterioration in wire drawing workability, an upper limit of the Mo content is set to 0.5 %. The upper limit thereof is preferably not more than 0.3 %.

Zr: not more than 0.1 %

[0031] Zr is an element contributing to the refinement of the metal microstructure, and the suppression of transformation into ferrite as with the case of V, and Zr can therefore be added as necessary. A preferable lower limit of Zr content is 0.010 %. However, because excessive addition of Zr will cause deterioration in wire drawing workability, an upper limit of the Zr content is set to 0.1 %. The upper limit thereof is preferably not more than 0.05 %.

Mg: not more than 5 ppm

[0032] Mg is an element acting so as to soften oxides to thereby enhance wire drawing workability, and Mg can therefore be added as necessary. A preferable lower limit of Mg content is 0.1 ppm. However, because excessive addition of Mg will cause oxides thereof to undergo a change in quality to thereby rather deteriorate wire drawing workability, an upper limit of the Mg content is set to 5 ppm. The upper limit thereof is preferably not more than 2 ppm.

Ca: not more than 5 ppm

[0033] Ca is an element acting so as to soften oxides as with the case of Mg, and Ca can therefore be added as necessary. A preferable lower limit of Ca content is 0.3 ppm. However, because excessive addition of Ca will cause deterioration in wire drawing workability, an upper limit of the Ca content is set to 5 ppm. The upper limit thereof is preferably not more than 2 ppm.

REM: not more than 1.5 ppm

[0034] REM acts so as to soften oxides as with the case of Mg, and REM can therefore be added as necessary. A preferable lower limit of REM content is 0.1 ppm. However, because excessive addition of REM will cause deterioration in wire drawing workability, an upper limit of the REM content is set to 1.5 ppm. The upper limit thereof is preferably not more than 0.5 ppm.

B: not more than 15 ppm

[0035] B is an element capable of enhancing hardenability, and addition of B enables the transformation into ferrite to be suppressed. A preferable lower limit of B content is 3 ppm. However, because excessive addition of B causes supercooled structures prone to be easily formed, thereby adversely affecting wire drawing workability, an upper limit of the B content is set to 15 ppm. The upper limit thereof is preferably not more than 12 ppm.

[0036] Next, the metal microstructure of the wire rod according to the invention is described hereinafter. The wire rod according to the invention has a feature in that the area ratio of the second-phase ferrite is not more than 11.0 %. Herein, "the second-phase ferrite" according to the invention refers to ferrite in a region without pearlite (lamellar structure of ferrite and cementite) formed therein, as indicated by respective arrows in Fig. 1 showing an SEM photograph of a cross-sectional face of the wire rod. Further, because there are times when it is difficult to distinguish the second-phase ferrite from pearlite, "the second-phase ferrite" according to the invention is more specifically defined as "BCC - Fe crystal grains in a region surrounded by a boundary differing in misorientation angle by not less than 10 degrees from the periphery of the region, an area ratio of cementite present in the respective BCC - Fe crystal grains being not more than 6 %".

[0037] "The area ratio of the second-phase ferrite", according to the invention, refers to an area ratio (%) of the second-phase ferrite to an observed visual field of the cross-sectional face of the wire rod, magnified 500 to 1500 times by the scanning electron microscope (SEM), that is, (an area of the second-phase ferrite within the observed visual field / an area of the observed visual field in whole) x 100. In this case, the area of the second-phase ferrite can be found by use of image analysis software, for example, {Image - Pro (Ver 4.0)} developed by Media Cybernetics. Further, since there occurs variation in the area ratio of the second-phase ferrite by the visual field as observed, a mean value of several values thereof, found by observing not less than eight visual fields selected at random, is adopted as a value of the area ratio of the second-phase ferrite, according to the invention.

[0038] The inventor, et al. have found out that a wire rod excellent in resistance to wire-break can be obtained by controlling the area ratio of the second-phase ferrite of the wire rod to not more than 11 %, preferably 10.0 %, and more preferably not more than 9 %. A mechanism causing the above is not clearly known, however, the mechanism can be presumed to be as follows. The invention, however, is not to be limited in scope to the mechanism presumed as described hereunder.

[0039] With a carbon steel wire rod to be subjected to drawing, such as the wire rod according to the invention, the primary constituent of the metal microstructure thereof is pearlite, however, in general, there also exists the region of the second-phase ferrite, without pearlite formed therein. It is presumed that strain concentration occurs to the second-phase ferrite lower in strength than pearlite when drawing is applied, so that voids are prone to occur thereto. The voids each can become a starting point of wire break. Accordingly, it is reasoned that resistance to wire break can be enhanced by decreasing the second-phase ferrite that is low in strength and is susceptible to the strain concentration.

[0040] Further, the wire rod according to the invention has a feature in that the same comprises a pearlite structure wherein the pearlite lamellar spacing is not less than 120 μm , preferably not less than 140 μm , and more preferably not less than 170 μm . The wire rod according to the invention can at times include bainite, and / or martensite besides the second-phase ferrite, however, pearlite is the primary constituent of the metal microstructure thereof. In the case of bainite, and / or martensite being in existence, a ratio of a total area of those microconstituents is preferably not more than 5 %, more preferably not more than 2 %, and still more preferably, bainite, and martensite do not in effect exist.

[0041] With the invention, "the pearlite lamellar spacing" refers to a thickness of a lamellar layer in pearlite, composed of a pair of a ferrite layer and a cementite layer, in pearlite. However, since there occurs variation in the pearlite lamellar spacing by the position for observation of the metal microstructure, what has been found in the following manner is defined as a value of "the pearlite lamellar spacing" according to the invention.

[0042] First, not less than six photographs of the cross-sectional face of the wire rod, as observed and magnified 3000 to 10,000 times by the SEM, are taken. As shown in Fig. 2, in a colony (a region where the ferrite layers and the cementite layers, in pearlite, are aligned in same direction) in the respective photographs taken by the SEM, a line segment orthogonal to the ferrite layers and the cementite layers is drawn, and the pearlite lamellar spacing in the colony as "a length of the line segment / the number of lamellar layers within the line segment" is found on the basis of the length of the line segment, and the number of the lamellar layers within the line segment. Then, by finding the pearlite lamellar spacings within not more than five pieces of the colonies, respectively, in the respective photographs taken by the SEM, the respective pearlite lamellar spacings within not less than thirty pieces of the colonies altogether are worked out, and a mean value thereof is defined as a value of "the pearlite lamellar spacing" according to the invention.

[0043] A mechanism whereby the resistance to the wire-break of the wire rod is enhanced if the pearlite lamellar spacing is not less than 120 μm is not clearly known, however, the mechanism can be presumed to be as follows. The invention, however, is not to be limited in scope to the mechanism presumed as described hereunder. Even if the second-phase ferrite exists in the wire rod, the strain concentration occurring to the second-phase ferrite will be mitigated in the case that a difference in strength between the second-phase ferrite and microstructure on the periphery thereof is small, so that occurrence of voids likely to cause wire-break is presumed to be checked. Further, it is reasoned that if the pearlite lamellar spacing becomes wider, strength of pearlite becomes lower, and a difference in strength between pearlite and the second-phase ferrite is rendered relatively small, so that this will probably contribute to enhancement in the resistance to the wire-break of the wire rod.

[0044] However, if the pearlite lamellar spacing becomes excessively wide, it is deemed that a likelihood of occurrence of the voids will become greater on the contrary. An upper limit of the pearlite lamellar spacing is therefore preferably

not more than 350 μm , more preferably not more than 300 μm , and still more preferably, not more than 280 μm .

[0045] With the invention, a location on the cross-sectional face, adopted for observation by the SEM, in order to find "the area ratio of the second-phase ferrite", and "the pearlite lamellar spacing", is specified as a location at $D/4$ on the cross-sectional face of the wire rod (D : diameter of the wire rod). The reason for this is to extract average data on the metal microstructure of the wire rod. Parts in the surface layer are subjected to effects of decarburization and central parts are subjected to effects of segregation and so forth, so that variations in the data, at those locations, tend to increase.

[0046] The wire rod according to the invention can be produced by, for example, a method described hereinafter (refer to Fig. 3). The wire rod according to the invention, however, is not limited to that produced by the method described hereinafter. First, a steel product meeting the requirements for the chemical components is heated up to 900 to 1250°C to be subsequently hot rolled at a temperature not lower than 780°C, and a finish-rolling temperature is controlled to not higher than 1100°C. This is because heating is insufficient with a heating temperature lower than 900°C, and conversely, if the heating temperature exceeds 1250°C, decarburization in the surface layer spreads, so that scales capable of adversely affecting the wire-drawing workability tend to become harder to peel off. Further, if a rolling temperature is lowered, decarburization in the surface layer is similarly promoted, and a lower limit temperature for hot rolling is therefore set to 780°C. Conversely, if the finish-rolling temperature exceeds 1100°C, this will render it difficult to control transformation of the metal microstructure by cooling and reheating, to be executed in a subsequent process step, so that an upper limit of the finish-rolling temperature is set to 1100°C.

[0047] A wire rod formed after the finish-rolling is water-cooled to a temperature range of 750 to 950°C, and is coiled up on conveying equipment, such as a Stelmor conveyor, to be then placed thereon. Temperature control executed after water-cooling is important for control of the transformation of the metal microstructure, taking place thereafter, and control of scales. If an ultimate temperature at the time of water-cooling is below 750°C, this will at times cause the supercooled structures to be formed in the surface layer, thereby adversely affecting the wire-drawing workability, and on the other hand, if the ultimate temperature exceeds 950°C, this will cause loss in deformability of scales, so that scales will peel off in the course of transportation, thereby creating a cause for rusting.

[0048] It is of particular importance from the viewpoint of obtaining the wire rod meeting the requirements for the metal microstructure, excellent in the wire-drawing workability, to cool the wire rod at an average cooling rate of not less than 20°C / sec within 20 sec from the coiling of the wire rod to thereby drop temperature of the wire rod to a minimum value point (T_1) in a temperature range of 550 to 630°C before raising the temperature of the wire rod up to a maximum value point (T_2) in a temperature range of 580 to 720°C, higher in value than T_1 , within 50 sec from the coiling of the wire rod. A reference time for "within 20 sec from the coiling" is a point in time when a rolled wire rod is coiled up in ring-like fashion to be placed on the conveying equipment, such as the conveyor. Further, since the wire rod is continuously coiled up, and is continuously cooled, there occurs time lag between the top part of the wire rod, coiled up, and the bottom part thereof, to be coiled up, with respect to a time when the wire rod is placed, and a time when the wire rod is cooled, respectively, however, respective measurements on time from the coiling up to the cooling are started upon the coiling of the respective part of the wire rod.

[0049] Since it is presumed that the second-phase ferrite prone to undergo strain concentration is formed at a relatively high temperature before pearlite transformation, formation of the second-phase ferrite can be suppressed by rapidly cooling the wire rod at the average cooling rate of not less than 20°C / sec down to a temperature region where ferrite is hard to be formed within 20 sec from the coiling of the wire rod. Further, because pearlite transformation nuclei in massive amounts are formed due to such rapid cooling, advantageous effect of the metal microstructure being micronized can be gained. However, if a cooling rate is excessively high, this will raise the risk of an increase in strength differential within the wire rod, due to localized formation of supercooled structures, and so forth, thereby causing deterioration in the wire drawing workability. Accordingly, the average cooling rate is preferably set to not more than 50°C / sec. Herein, "the average cooling rate", according to the invention, refers to a cooling rate found on the basis of a temperature difference between the wire rod temperature upon the coiling thereof (that is, the wire rod temperature after water-cooling) and T_1 , and a cooling time length required for the wire rod temperature at the time of the coiling to drop down to T_1 .

[0050] Further, if the wire rod is cooled down only to the minimum value point (T_1) in excess of 630°C in such a cooling process step as described above, it is not possible to sufficiently suppress the formation of the second-phase ferrite, so that coarse grains having adverse effects on the wire-drawing workability become prone to be easily formed. On the contrary, if the wire rod is excessively cooled down to the minimum value point (T_1) below 550°C, this will lead to an increase in strength differential within the wire rod, due to the formation of the supercooled structures, and so forth.

[0051] After the wire rod is cooled down to T_1 in the temperature range during the cooling process step, the wire rod is reheated to thereby cause the pearlite transformation to occur. On this occasion, by increasing the wire rod temperature to a high temperature at 580°C or higher, the pearlite lamellar spacing can be rendered wider. Further, it is presumed that the higher a transformation temperature, the wider the pearlite lamellar spacing can become, however, ductility becomes excessively low at the transformation temperature in excess of 720°C, raising the risk of the wire drawing workability undergoing deterioration contrary to expectation.

[0052] It is deemed possible that the pearlite lamellar spacing can be rendered wider by slowly cooling the wire rod

as usual, or holding the wire rod at a constant temperature without rapidly cooling the same after the coiling thereof on the conveying equipment. However, there is a likelihood that the metal microstructure becomes coarser because a rate at which the pearlite transformation nuclei are formed is low in a high temperature region, thereby causing adverse effects on the wire drawing workability. Hence, the wire rod whose metal microstructure is fine, and has a wide pearlite lamellar spacing can be provided by a production method according to the invention, comprising a step of rapidly cooling a wire rod once after coiling thereof on a conveying equipment before reheating the same, thereby causing pearlite transformation to proceed in a high temperature region.

Working Examples

[0053] The invention is more specifically described hereinafter with reference to working examples. It is to be pointed out, however, that the invention be not limited in scope by the working examples described hereunder, and that various changes and modifications may be obviously made in the invention in light of teachings described hereinbefore and hereinafter without departing from the spirit and scope thereof.

1. Production of Wire Rods

[0054] Hot rolled wire rods Nos. 1 to 29, each 5.5 mm in diameter, were produced under various conditions shown in Table 2, with the use of steel products S1 to S16, having chemical compositions shown in Table 1, respectively. More specifically, the steel products each were heated to a range of 978 to 1205°C in a heating furnace to be hot rolled at a rolling temperature not lower than 807°C, and to be finish-rolled at a temperature not higher than 1068°C, thereby being formed into the respective wire rods. The wire rods each were water-cooled to a temperature in a range of 798 to 948°C, and were subsequently coiled up and placed on the Stelmor conveyer (a cooling bed) to be continuously cooled. In the course of cooling on the Stelmor conveyer, temperature of the wire rod was lowered to the minimum value point (T1) in a temperature range of 515 to 682°C within 20 sec from the coiling of the wire rod. An average cooling rate during this time period was in a range of 13 to 99°C / sec. Subsequently, the temperature of the wire rod was raised from T1 up to the maximum value point (T2) in a temperature range of 584 to 705°C. Further, some of the wire rods were continuously and slowly cooled from T1 without being heated up from T1.

Table 1 - 1

Chemical components 1 (basic components) of steel products (mass %)								
Steel Products	C	Si	Mn	P	S	Al	N	O
S1	0.60	0.20	0.49	0.007	0.008	0.0011	0.0021	0.0012
S2	0.61	0.19	0.48	0.005	0.007	0.0005	0.0024	0.0011
S3	0.70	0.20	0.50	0.005	0.006	0.0005	0.0024	0.0010
S4	0.72	0.19	0.83	0.006	0.005	0.0278	0.0032	0.0013
S5	0.80	0.20	0.50	0.006	0.004	0.0007	0.0028	0.0010
S6	0.81	0.20	0.51	0.015	0.014	0.0010	0.0030	0.0011
S7	0.81	0.19	0.50	0.005	0.007	0.0004	0.0027	0.0010
S8	0.82	0.20	0.50	0.004	0.004	0.0008	0.0022	0.0009
S9	0.89	1.77	0.49	0.005	0.004	0.0010	0.0031	0.0011
S10	0.90	0.22	0.49	0.006	0.005	0.0009	0.0025	0.0010
S11	0.92	0.19	0.49	0.004	0.005	0.0006	0.0027	0.0011
S12	1.05	0.18	0.49	0.006	0.005	0.0005	0.0025	0.0010
S13	0.81	2.30	0.50	0.005	0.005	0.0350	0.0031	0.0015
S14	0.81	0.20	1.55	0.011	0.022	0.0254	0.0037	0.0014
S15	0.81	0.21	0.49	0.021	0.013	0.0279	0.0075	0.0015
S16	1.20	0.19	0.50	0.008	0.007	0.0244	0.0050	0.0014

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Table 1 - 2

Chemical components 2 (basic components) of steel products (mass %)												
Steel Products	mass %								mass ppm			
	Cr	Cu	Ni	V	Ti	Nb	Mo	Zr	B	Mg	Ca	REM
S1	0.01	0.02	0.01	0.0021	0.0710	-	-	-	11	0.1	1.1	-
S2	-	0.01	-	-	-	-	-	-	-	-	-	-
S3	-	-	-	0.0022	0.0010	0.0300	-	0.0240	8	0.2	-	-
S4	0.02	0.01	0.02	0.0018	-	-	-	-	-	0.1	1.0	0.1
S5	0.01	-	0.30	0.0017	-	0.0510	-	-	3	0.1	0.7	-
S6	0.78	-	-	0.1100	-	-	0.21	-	-	0.2	1.2	0.1
S7	-	0.01	0.02	-	-	-	-	-	-	0.1	1.1	0.1
S8	0.01	-	-	-	-	-	-	-	-	0.1	-	-
S9	0.31	0.21	0.20	0.2170	0.0011	-	-	-	-	0.1	0.8	-
S10	0.01	-	-	-	-	-	-	-	-	-	-	-
S11	0.20	0.18	-	-	-	-	-	-	-	0.1	1.0	0.1
S12	0.22	0.11	0.01	-	-	-	-	-	10	0.1	1.4	0.1
S13	0.70	0.21	0.15	0.3110	-	-	-	-	-	0.1	0.7	-
S14	0.51	0.10	0.11	-	-	-	-	-	-	-	-	-
S15	-	-	-	-	-	0.1050	-	-	11	-	-	-
S16	1.60	-	-	-	-	-	-	-	-	-	-	-

Table 2 - 1

wire rod	steel product	heating temperature (°C)	lowest hot-roll temperature (°C)	finish-rolling temperature (°C)	wire rod temperature after water-cooling (°C)	average cooling rate (°C/sec)
1	S1	1151	933	989	940	78
2	S1	1150	930	991	948	14
3	S2	1148	945	993	845	75
4	S2	1150	941	990	847	24
5	S2	1151	940	992	850	35
6	S3	1175	946	1068	911	93
7	S3	1172	944	1059	908	18
8	S4	1150	940	1033	908	94
9	S4	1154	938	1031	912	97
10	S4	1151	935	1030	921	99
11	S5	1022	855	982	910	75
12	S5	1020	857	977	915	51
13	S5	1018	861	978	908	16
14	S6	1025	843	972	914	70

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(continued)

5	wire rod	steel product	heating temperature (°C)	lowest hot-roll temperature (°C)	finish-rolling temperature (°C)	wire rod temperature after water-cooling (°C)	average cooling rate (°C/sec)
	15	S6	1024	840	981	908	76
	16	S6	1031	851	988	916	54
10	17	S7	1020	807	934	798	61
	18	S7	1022	811	930	805	58
	19	S8	978	813	933	823	56
15	20	S9	1055	905	976	921	50
	21	S10	1054	912	975	917	48
	22	S11	1151	977	1064	922	47
	23	S11	1148	971	1058	914	57
20	24	S11	1152	972	1045	912	13
	25	S12	1205	968	1037	915	45
	26	S13	1148	941	991	905	59
25	27	S14	1145	940	994	902	58
	28	S15	1147	952	987	908	55
	29	S16	1142	951	992	905	54

Table 2 - 2

35	wire rod	steel product	minimum value point T1		maximum value point T2	
			time from coiling of the wire rod (sec)	temperature (°C)	time from coiling of the wire rod (sec)	temperature (°C)
	1	S1	5.0	550	18.0	688
	2	S1	19.0	682	29.0	701
	3	S2	3.5	583	17.0	691
40	4	S2	10.0	607	15.0	678
	5	S2	7.0	605	15.0	684
	6	S3	3.5	586	15.0	692
45	7	S3	18.0	584	28.0	689
	8	S4	3.5	579	12.0	664
	9	S4	3.5	573	12.0	599
	10	S4	4.0	525	11.0	662
50	11	S5	4.0	610	10.0	701
	12	S5	5.5	642	11.0	703
	13	S5	19.0	604	28.0	697
55	14	S6	5.0	564	18.0	645
	15	S6	5.0	528	17.0	584
	16	S6	5.0	646	slow cooling (T1 > T2)	

(continued)

wire rod	steel product	minimum value point T1		maximum value point T2	
		time from coiling of the wire rod (sec)	temperature (°C)	time from coiling of the wire rod (sec)	temperature (°C)
17	S7	3.5	585	10.0	705
18	S7	3.5	602	slow cooling (T1 > T2)	
19	S8	3.5	627	10.0	698
20	S9	7.0	571	18.0	685
21	S10	7.0	581	17.0	683
22	S11	7.0	593	17.0	701
23	S11	7.0	515	20.0	645
24	S11	18.0	678	24.0	688
25	S12	7.0	600	14.0	675
26	S13	5.5	581	12.0	664
27	S14	5.5	583	12.0	665
28	S15	5.5	606	12.0	657
29	S16	5.5	608	12.0	661

2. Measurement on Area Ratio of Second-phase Ferrite, and Pearlite Lamellar spacing

[0055] As to the respective wire rods obtained as above, the area ratio of the second-phase ferrite, and the pearlite lamellar spacing were measured as follows:

First, the wire rods each were cut, and resin was embedded therein such that the cross-sectional face of the wire rod can serve as an evaluation face, wet polishing by use of an emery paper and diamond powders was applied to the cross-sectional face thereof, and a metal microstructure of the cross-sectional face thereof was exposed by etching with Picral, thereby preparing a specimen for observation. Then, the metal microstructure of the wire rod, at the location corresponding to $D/4$ on the cross-sectional face of the wire rod (D : diameter of the wire rod) was observed by the SEM

In measuring the area ratio of the second-phase ferrite, respective SEM photos of not less than 8 visual fields, as magnified 500 to 1500 times by the SEM, were taken. On the basis of the respective SEM photos obtained, the area ratio of the second-phase ferrite was worked out by carrying out image analysis with the use of the image analysis software, {Image - Pro (Ver 4. 0)}, thereby having found a mean value of the area ratios of the second-phase ferrite, worked out according to those SEM photos, respectively. Measurement results are shown in Table 3. In measurement of the pearlite lamellar spacing, respective SEM photographs of not less than 6 visual fields of the cross-sectional face of each of the wire rod, as magnified 3000 to 10, 000 times by the SEM, were taken. On the basis of the respective SEM photos obtained, the respective pearlite lamellar spacings within not more than five, pieces of the colonies were found, thereby having worked out a mean value of the pearlite lamellar spacings as found from not less than thirty pieces of the colonies altogether. Measurement results are shown in Table 3.

3. Evaluation on Wire drawing Workability

[0056] With respect to the respective wire rods, wire drawing workability was evaluated as follows.

[0057] First, chemical descaling (acid cleaning) or mechanical descaling (MD), shown in Table 3, as a descaling treatment to provide a pretreatment for wire-drawing, was applied to the respective wire rods (5.5 mm in diameter). In the case of acid cleaning, the respective wire rods were cleaned in hydrochloric acid to be subsequently treated with a phosphate. In the case of mechanical descaling (MD), bending stress was imparted to the respective wire rods with the use of a bending roller provided alongside a wire drawing machine to thereby remove scales, and subsequently, borax was applied to the respective wire rods. The respective wire rods after removal of the scales by the acid cleaning or the mechanical descaling were subjected to wire-drawing using a Na-based lubricant.

[0058] Thereafter, dry wire-drawing with the use of a continuous-wire-drawing machine was applied to the respective wire rods on the following wire drawing conditions (1) to (3), respectively, until a final diameter is reduced to 0.9 mm. The higher a wire-drawing rate is, and the less the number of dies is, that is, according as the wire-drawing condition turns from (1) to (3), the higher productivity of drawing will become, however, the wire-drawing condition will become severer.

The wire-drawing condition (1) : final wire-drawing rate at 600 m / min, the number of dies; 14 pieces

The wire-drawing condition (2) : final wire-drawing rate at 800 m / min, the number of dies; 14 pieces

The wire-drawing condition (3) : final wire-drawing rate at 800 m / min, the number of dies; 12 pieces

[0059] Wire-drawing under the respective wire-drawing conditions was applied to 50 tons each of the wire rods, and evaluation was made on whether or not a wire-break occurs, and an extent of die-wear, as criteria for the wire drawing workability. As to the evaluation on the extent of the die-wear, symbol (X) indicates the case where any of the dies were broken in the course of wire-drawing, symbol (Δ) indicates the case where none of the dies were broken in the course of drawing 50 tons each of the wire rods, but the dies were worn out, requiring replacement after the wire-drawing, and symbol (O) indicates the case where none of the dies were broken, and there is no necessity of replacing the dies, due to the wear thereof, after the wire-drawing of 50 tons each of the wire rods. Further, symbol (-) indicates the case where the evaluation on the extent of the die-wear was not applicable due to occurrence of wire-break. Measurement results are shown in Table 3.

Table 3

wire rod	steel product	area ratio of second-phase ferrite (%) ^{*1)}	pearlite lamellar spacing (μ m)	descaling treatment	wire-drawing condition (1)		wire-drawing condition (2)		wire-drawing condition (3)	
					wire break	die life	wire break	die life	wire break	die life
1	S1	7.8	215	MD	No	o	No	o	No	o
2	S1	15.5	201	MD	Yes	-	Yes	-	Yes	-
3	S2	9.1	232	acid cleaning	No	o	No	o	No	o
4	S2	10.2	202	acid cleaning	No	o	No	o	Yes	-
5	S2	9.4	214	acid cleaning	No	o	No	o	No	o
6	S3	6.5	227	MD	No	o	No	o	No	o
7	S3	10.8	210	MD	No	o	No	o	Yes	-
8	S4	2.7	192	MD	No	o	No	o	No	o
9	S4	3.7	128	MD	No	o	No	o	No	o
10	S4	2.2	118	MD	Yes	-	Yes	-	Yes	-
11	S5	3.4	285	MD	No	o	No	o	No	o
12	S5	12.1	305	MD	Yes	-	Yes	-	Yes	-
13	S5	10.2	275	MD	No	o	No	o	Yes	-
14	S6	1.2	148	MD	No	o	No	o	No	o
15	S6	1.5	75	MD	Yes	-	Yes	-	Yes	-
16	S6	11.5	127	MD	Yes	-	Yes	-	Yes	-
17	S7	3.6	303	acid cleaning	No	o	No	o	No	o

(continued)

wire rod	steel product	area ratio of second-phase ferrite (%) ^{*1)}	pearlite lamellar spacing (μm)	descaling treatment	wire-drawing condition (1)		wire-drawing condition (2)		wire-drawing condition (3)	
					wire break	die life	wire break	die life	wire break	die life
18	S7	5.2	115	acid cleaning	Yes	-	Yes	-	Yes	-
19	S8	4.7	245	acid cleaning	No	o	No	o	No	o
20	S9	4.1	199	MD	No	o	No	o	No	o
21	S10	4.7	180	MD	No	o	No	o	No	o
22	S11	5.0	231	MD	No	o	No	o	No	o
23	S11	1.0	108	MD	Yes	-	Yes	-	Yes	-
24	S11	11.2	198	MD	Yes	-	Yes	-	Yes	-
25	S12	2.2	177	MD	No	o	No	o	No	o
26	S13	4.7	172	MD	Yes	-	Yes	-	Yes	-
27	S14	3.9	147	MD	Yes	-	Yes	-	Yes	-
28	S15	4.7	184	MD	Yes	-	Yes	-	Yes	-
29	S16	3.5	141	MD	Yes	-	yes	-	Yes	-
*1) Remarks: With respect to all the wire rods except for the wire rods Nos. 23, and 27, the remaining metal microstructure is, in effect, pearlite; the metal microstructure of the wire rod No. 23: 94 % pearlite, 5 % martensite; the metal microstructure of the wire rod No. 27: 93.1 % pearlite, 3 % martensite										

[0060] It has turned out from the results shown in Table 3 that the respective wire rods Nos. 1, 3, 5, 6, 8, 9, 11, 14, 17, 19, 20, 21, 22 and 25, meeting the requirements for the chemical components as well as the metal microstructure, according to the invention, had no wire-break, and little die wear even when processed under the severe wire-drawing condition (3). Accordingly, it is evident that those wire rods each had outstandingly excellent wire drawing workability.

[0061] It is also shown that the respective wire rods Nos. 4, 7, and 13, meeting the requirements for the chemical components as well as the metal microstructure, according to the invention, had no wire-break, and little die wear when processed under the wire drawing conditions (1) and (2), respectively. Accordingly, those wire rods as well each had excellent wire drawing workability. However, those wire rods each had wire-break when processed under the wire drawing condition (3). It is deemed that this was due to a relatively high area ratio of the second-phase ferrite.

[0062] In the cases of the respective wire rods that did not meet the requirements for the area ratio of the second-phase ferrite, according to the invention, Nos. 2, 12, 16, and 24, and in the cases of the respective wire rods that did not meet the requirements for the pearlite lamellar spacing, according to the invention, Nos. 10, 15, 18, and 23, wire-break occurred thereto even when processed under the mild wire-drawing condition (1) although all those wire rods met the requirements for the chemical components, according to the invention.

[0063] Meanwhile, in the cases of the wire rods that did not meet the requirements for the chemical components, more specifically, in the cases of the wire rod No. 26 whose Si content, and Al content are outside respective specified ranges, the wire rod No. 27 whose Mn content, and S content are outside respective specified ranges, the wire rod No. 28 whose P content, N content, and Nb content are outside respective specified ranges, and the wire rod No. 29 whose C content is outside a specified range, wire-break occurred thereto even when processed under the mild wire-drawing condition (1) although all those wire rods met the requirements for the metal microstructure, according to the invention.

[0064] As described in the foregoing, the wire rod with excellent resistance to wire-break, causing little die-wear, and excelling in the wire-drawing workability can be obtained by adequately controlling the requirements for the metal microstructure thereof (the area ratio of the second-phase ferrite, and the pearlite lamellar spacing) and the requirements for the chemical components thereof.

Claims

1. A wire rod made of steel comprising:

C: 0.6 to 1.1 % (mass %, applicable to all components referred to hereunder);
 Si: 0.1 to 2.0% ;
 Mn: 0.1 to 1 %;
 P: not more than 0.020 % (0 % exclusive);
 S: not more than 0.020 % (0 % exclusive);
 N: not more than 0.006 % (0 % exclusive);
 Al : not more than 0.03 % (0 % exclusive); and
 O: not more than 0.003 % (0 % exclusive), the balance being Fe and unavoidable impurities,

said wire rod comprising a pearlite structure wherein an area ratio of a second-phase ferrite is not more than 11.0 %, and a pearlite lamellar spacing is not less than 120 μm .

2. The wire rod according to claim 1, further comprising not more than 1.5 % Cr (0 % exclusive).

3. The wire rod according to claims 1 or 2, further comprising not more than 1 % Cu (0 % exclusive), and / or not more than 1 % Ni (0 % exclusive).

4. The wire rod according to any of claims 1 to 3, further comprising at least one element selected from the group consisting of not more than 0.30 % (0 % exclusive) V, not more than 0.1% (0 % exclusive) Ti, not more than 0.10 % (0 % exclusive) Nb, not more than 0.5 % (0 % exclusive) Mo, and not more than 0.1 % (0 % exclusive) Zr.

5. The wire rod according to any of claims 1 to 4, further comprising at least one element selected from the group consisting of not more than 5 ppm (0 ppm exclusive) Mg, not more than 5 ppm (0 ppm exclusive) Ca, and not more than 1.5 ppm (0 ppm exclusive) REM.

6. The wire rod according to any of claims 1 to 5, further comprising not more than 15 ppm B.

7. A method for producing a wire rod, comprising the steps of:

heating a steel product meeting requirements for chemical components, specified in any of claims 1 to 6, to a temperature in a range of 900 to 1250°C;
 hot rolling the steel product at a temperature not lower than 780°C, and finish-rolling the same at a temperature not higher than 1100°C to be thereby formed into a wire rod;
 water-cooling the wire rod to a temperature range of 750 to 950°C before coiling the same up to be placed on conveying equipment;
 cooling the wire rod at an average cooling rate of not less than 20°C / sec within 20 sec from coiling of the wire rod to thereby drop temperature of the wire rod to a minimum value point (T1) in a temperature range of 550 to 630°C; and
 subsequently heating the wire rod to thereby raise the temperature of the wire rod up to a maximum value point (T2) in a temperature range of 580 to 720°C, higher in value than the minimum value point (T1), within 50 sec from the coiling of the wire rod.

FIG. 1

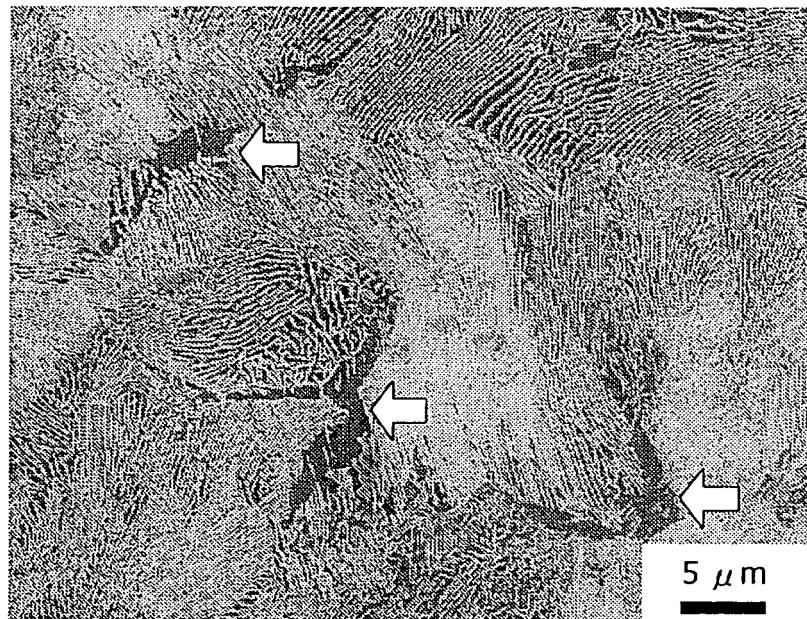


FIG. 2

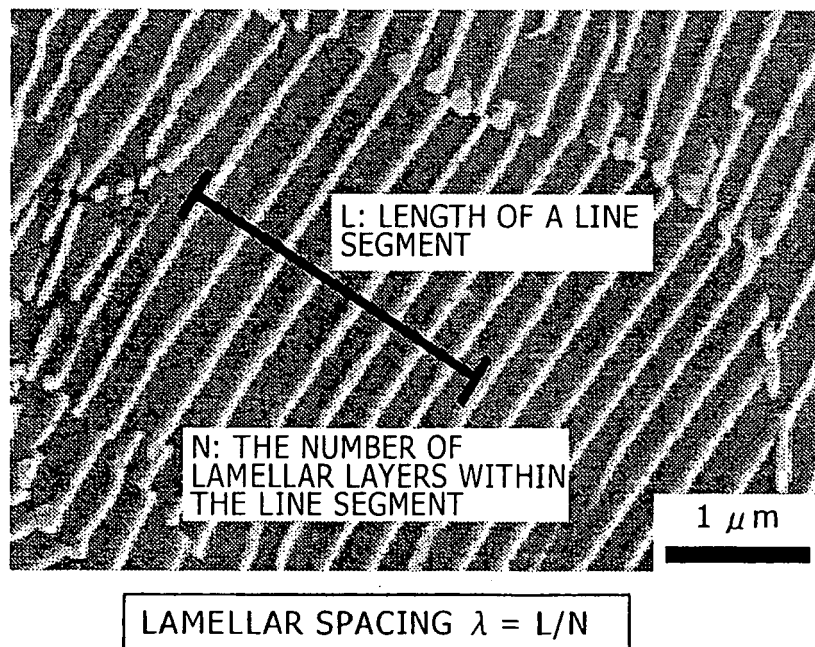
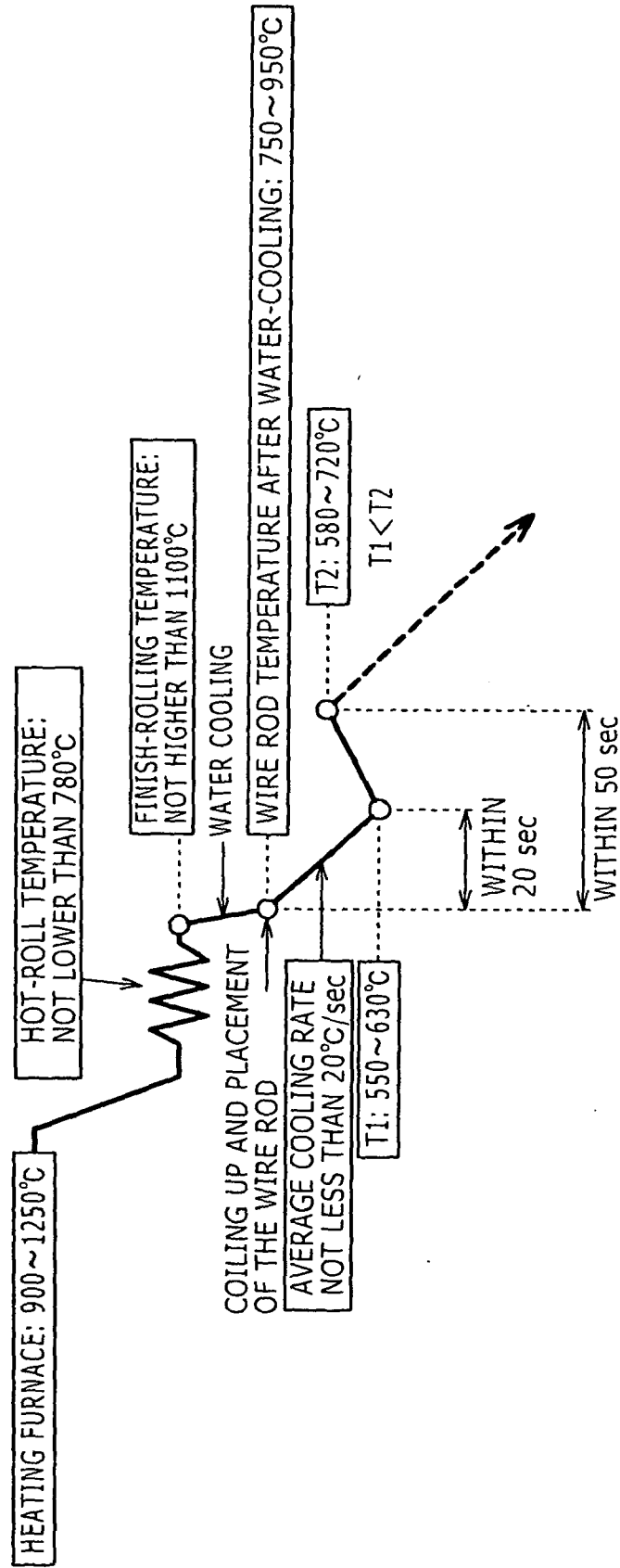


FIG. 3





European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
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Place of search Munich		Date of completion of the search 3 August 2007	Examiner Gavriliu, Alexandru
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