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(54) **HIGH-CARBON STEEL WIRE HAVING SUPERIOR WIRE DRAWING PROPERTIES AND METHOD FOR PRODUCING SAME**

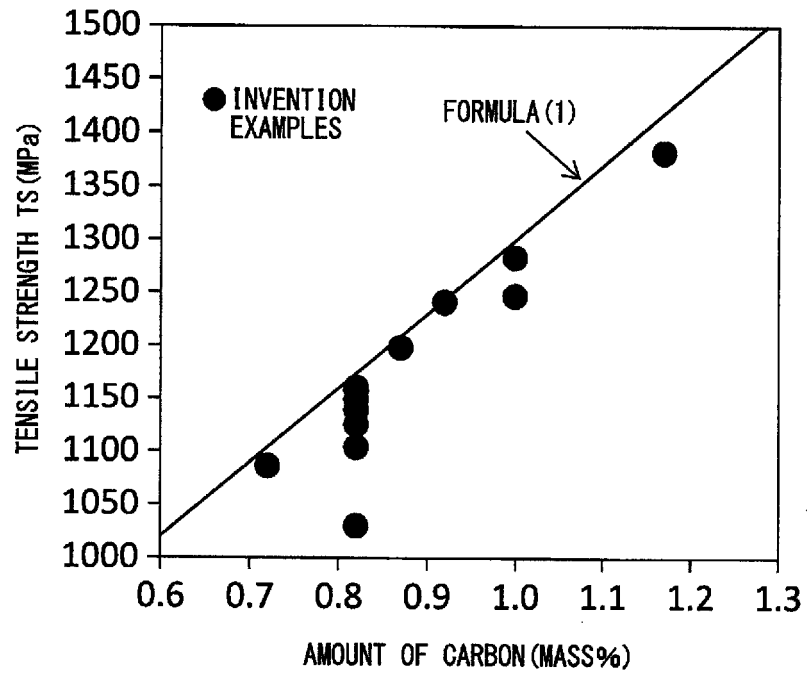
(57) The present invention provides a wire rod having good wire drawing characteristics stably in actual production and a method for production of such wire rod. The wire rod has a chemical composition including, by mass%, C: 0.7 to 1.2%, Si: 0.1 to 1.5%, Mn: 1.0% or less, N: 0.005ppm or less, and a balance of Fe and unavoidable impurities, wherein 80% or more of a microstructure is a bainite structure and a remaining microstructure is a nonbainite structure in a cross-section of the wire rod, wherein a full width at half maximum of a (211) crystal face of a ferrite phase in the structure of the wire rod cross-section is 0.6° or less, wherein a tensile strength TS (MPa) and reduction of area RA (%) respectively satisfy the following formula (1) and the following formula (2), and wherein a standard deviation of hardness distribution of Vickers hardness (Hv) in the cross-section is less than 6.

$$TS \leq 580 + 700 \times [C] \quad \dots (1)$$

$$RA \geq 100 - 46 \times [C] - 18 \times [Mn] - 10 \times [Cr] \quad \dots (2)$$

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FIG. 1



Description

Technical Field

5 **[0001]** The present invention relates to a high carbon steel wire rod requiring primary wire drawing before final patenting or oil tempering or a high carbon steel wire rod for use in the manufacture of an ACSR (aluminum conductor steel reinforced) and rope, and relates to a method for production of the same.

Background Art

10 **[0002]** For secondary working of a wire rod, mainly the drawing process is used. In general, pearlite steel heat-treated by the Stelmor process or lead patenting process is used. In particular, ultrafine wire of STC (steel cord) or small diameter rope is produced by the steps of reducing the wire rod in size to a predetermined wire diameter by intermediate patenting or reducing the rolled wire size so as to decrease the strain in wire drawing.

15 **[0003]** On the other hand, as means for reducing the strain in wire drawing itself, use of a low strength pearlite structure or bainite structure has been known.

[0004] In these structures, the initial strength of the wire rod and the rise in tensile strength due to wire drawing are kept low. From the viewpoint of reducing the drawing force at the time of drawing work and of control of the amount of heat generated during work, the method for production of a bainite wire rod by two-stage transformation has been proposed, and was expected in terms of superiority in basic units of processing and in material quality (for example, see PLTs 1 to 3).

20 **[0005]** Although heat treatment for controlling the ratio of microstructures in the bainite wire has been disclosed in the above-mentioned method for production, the microstructural factors for stably lowering the strength have not been elucidated.

25 Citation List

Patent Literature

30 **[0006]**

- PLT 1. Japanese Patent Publication No. 06-330240A
- PLT 2. Japanese Patent Publication No. 06-73502A
- PLT 3. Japanese Patent Publication No. 06-73501A

35 Summary of Invention

Technical Problem

40 **[0007]** The present invention was made taking note of the above situation and has as its object the provision of a wire rod having stable and good wire drawing characteristics in actual production and a method for production of that wire rod.

Solution to Problem

45 **[0008]** The inventions disclosed in PLTs 1 to 3 all hold the temperatures of the rods at 350°C to 500°C for within a certain time so as start partial bainite transformation from the supercooled austenite structure, then cause the temperature to rise and hold the temperatures of the rods there until the bainite transformation completely ends to thereby produce a bainite structure with precipitation of coarse cementite. That is, the inventions disclosed in PLTs 1 to 3 are all characterized by softening the upper bainite structure during two-stage heat treatment. They are not directed to completion of the bainite transformation by single-stage heat treatment.

50 **[0009]** The inventors studied the softening mechanism in two-stage cooling so as to obtain good wire drawing characteristics in bainite wire and discovered that (i) by holding the temperature in the first-stage heat treatment until the bainite transformation is completed, the bainite fraction rises and the cementite can be made to uniformly disperse in the bainite structure, (ii) even if the initial structure is a hard bainite structure alone, the targeted wire rod strength can achieved due to the annealing effect by heating in the two-stage cooling, and (iii) there is a structural fraction enabling reduction of the hardening rate during wire drawing without being influenced by the nonbainite structure, and thereby completed the present invention.

55 **[0010]** The present invention was made based on the above discoveries and has as its gist the following:

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5 **[0011]** (1) A wire rod excellent in wire drawing ability having a chemical composition comprising, by mass%, C: 0.7 to 1.2%, Si: 0.1 to 1.5%, and Mn: 1.0% or less, N: 0.005% or less, and a balance of Fe and unavoidable impurities, wherein 80% or more of a microstructure is a bainite structure and a remaining microstructure is a nonbainite structure in a cross-section of the wire rod, wherein a full width at half maximum of a (211) crystal face of a ferrite phase in the microstructure of the wire rod cross-section is 0.6° or less, wherein a tensile strength TS (MPa) and reduction of area RA (%) respectively satisfy a following formula (1) and a following formula (2), and wherein a standard deviation of hardness distribution of Vickers hardness (Hv) in the cross-section is less than 6.

$$10 \quad TS \leq 580 + 700 \times [C] \quad \dots (1)$$

$$RA \geq 100 - 46 \times [C] - 18 \times [Mn] - 10 \times [Cr] \quad \dots (2)$$

15 where, [C], [Mn], and [Cr] respectively indicate the mass% of C, Mn, and Cr.

[0012] (2) The wire rod excellent in wire drawing ability according to (1) wherein the chemical composition further contains, by mass%, one or more of Cr: 1.0% or less, Ni: 1.0% or less, Cu: 0.1% or less, V: 0.1% or less, Mo: 0.5% or less, Ti: 0.05% or less, Nb: 0.1% or less, Al: 0.1% or less, Ca: 0.05% or less, and B: 0.005% or less.

20 **[0013]** (3) A method for production of a wire rod excellent in wire drawing ability according to (1) or (2) comprising hot rolling a billet of a chemical composition according to (1) or (2) into a wire rod, then winding the wire rod into a coil at 850 to 1050°C, next immersing the wire rod in 300 to 475°C molten salt or molten lead and completing bainite transformation to obtain a bainite fraction of 80% or more, and then immersing the wire rod in 550 to 650°C molten salt or molten lead for 1 second or more.

25 **[0014]** (4) A method for production of a wire rod excellent in wire drawing ability according to (1) or (2) comprising heating a wire rod of a chemical composition according to (1) or (2) to 850°C or more, then immersing the wire rod in 300 to 475°C sand, molten salt, or molten lead for patenting to obtain a bainite structure of 80% or more in a cross-section of the wire rod, then using sand, molten salt, molten lead, or resistance heating or induction heating to heat the wire rod at 550 to 650°C for 1 second or more.

30 Advantageous Effects of Invention

[0015] According to the present invention, based on the discoveries relating to the softening mechanism of bainite and the microstructural fraction enabling reduction of the work hardening rate, a wire rod excellent in wire drawing characteristics is provided. Brief Description of Drawings

35 **[0016]** FIG. 1 is a view showing one example of the relationship between the tensile strength TS (MPa) and amount of C (mass%).

Description of Embodiments

40 **[0017]** Below, the present invention will be explained.

[0018] The wire rod excellent in wire drawing ability of the present invention (below, sometimes referred to as "the wire rod of the present invention") is characterized by having a chemical composition comprising, by mass%, C: 0.7 to 1.2%, Si: 0.1 to 1.5%, Mn: 1.0% or less and a balance of Fe and unavoidable impurities, in which 80% or more of a microstructure is a bainite structure and a remaining microstructure is a nonbainite structure in the cross-section of the wire rod, a full width at half maximum of a (211) crystal face of a ferrite phase in the structure of the wire rod cross-section is 0.6° or less, further a tensile strength TS (MPa) and reduction of area RA (%) respectively satisfy the following formula (1) and the following formula (2), and a standard deviation of hardness distribution of Vickers hardness (Hv) in the cross-section is less than 6. Further, the "wire rod cross-section" means the cross-section vertical to the length direction of the wire rod.

$$50 \quad TS \leq 580 + 700 \times [C] \quad \dots (1)$$

$$55 \quad RA \geq 100 - 46 \times [C] - 18 \times [Mn] - 10 \times [Cr] \quad \dots (2)$$

where, [C], [Mn], and [Cr] respectively indicate the mass% of C, Mn, and Cr.

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[0019] First, the reasons for limitation of the chemical composition of the wire rod of the present invention will be explained. Below, "%" means mass%.

C: 0.7 to 1.2%

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[0020] C is an element increasing the cementite fraction and number density of cementite in the bainite structure and the dislocation density to raise the strength. If less than 0.7%, due to the ferrite transformation at the time of heat treatment, securing the bainite fraction becomes difficult, therefore the content is made 0.7% or more. Preferably, the content is 0.9% or more. On the other hand, if over 1.2%, proeutectoid cementite precipitates and the wire drawing ability deteriorates, so the content is made 1.2% or less. Preferably, the content is made 1.0% or less.

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Si: 0.1 to 1.5%

[0021] Si is a deoxidizing element. Further, it is an element of solid solution strengthening the ferrite. If less than 0.1%, at the time of galvanization, the alloy layer is not stably formed, so the content is made 0.1% or more. Preferably, the content is made 0.4% or more. On the other hand, if over 1.5%, the decarburization at the time of heating is promoted, the mechanical descaling ability deteriorates, and the precipitation of carbides at the time of the bainite transformation is also delayed, so the content is made 1.5% or less. Preferably, the content is made 1.2% or less.

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Mn: 1.0% or less

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[0022] Mn is a deoxidizing element. Further, it is an element improving the hardenability. It suppresses the formation of ferrite at the time of heat treatment, but if over 1.0%, the transformation is slowed and nontransformed structures may be formed, so the content is made 1.0% or less. Preferably, the content is made 0.7% or less. The lower limit is not particularly set, but from the viewpoint of increasing the ratio of the bainite structure, 0.2% or more is preferable, while 0.3% or more is more preferable.

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[0023] The wire rod of the present invention may contain, in addition to the above elements, one or more of Cr, Ni, Cu, V, Mo, Ti, Nb, Al, Ca, and B in suitable quantities in a range not impairing the characteristics of the wire rod of the present invention.

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Cr: 1.0% or less

[0024] Cr is an element improving the hardenability and an element which acts to suppress the ferrite transformation and pearlite transformation at the time of heat treatment. If over 1.0%, the transformation finish time becomes longer and also the mechanical descaling ability deteriorates, so the content is made 1.0% or less. Preferably, it is 0.7% or less. The lower limit includes 0%, but from the viewpoint of reliably obtaining the effect of addition, 0.05% or more is preferable.

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Ni: 1.0% or less

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[0025] Ni is an element improving the hardenability and an element suppressing ferrite transformation to increase the ratio of the bainite structure. If over 1.0%, the transformation finish time become longer, so the content is made 1.0% or less. Preferably, it is made 0.7% or less. The lower limit includes 0%, but from the viewpoint of reliably obtaining the effect of addition, 0.05% or more is preferable.

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Cu: 0.1% or less

[0026] Cu is an element improving the corrosion resistance. If over 0.1%, it reacts with S to cause CuS to segregate at the austenite grain boundaries, which causes scratches at the steel ingots or wire rods etc. in the process of production of wire rods, so the content is made 0.1% or less. Preferably, it is made 0.07% or less. The lower limit includes 0%, but from the viewpoint of reliably obtaining the effect of addition, 0.01% or more is preferable.

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V: 0.1% or less

[0027] V is an element acting to delay ferrite transformation in the solid solution state. If over 0.1%, it forms nitrides in the austenite structure and causes the hardenability to drop. Further, when raising the temperature after transformation, carbides precipitate and the wire falls in toughness. Therefore, the content is made 0.1% or less. Preferably, the content is made 0.05% or less, more preferably 0.03% or less. The lower limit includes 0%, but from the viewpoint of reliably

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obtaining the effect of addition, 0.01% or more is preferable.

Mo: 0.5% or less

5 **[0028]** Mo is an element improving the hardenability, suppressing ferrite transformation and pearlite transformation, and raising the ratio of the bainite structure. If over 0.5%, the transformation finish time becomes longer and also, when raising the temperature after transformation, carbides are formed and secondary hardening occurs, so the content is made 0.5% or less. Preferably, the content is made 0.3% or less. The lower limit includes 0%, but from the viewpoint of reliably obtaining the effect of addition, 0.1% or more is preferable.

10 Ti: 0.05% or less

15 **[0029]** Ti is an element reducing the γ -grain size and refining the subsequently formed structure and thereby contributes to improvement of the ductility. If over 0.05%, the effect of addition is saturated, so the content is made 0.05% or less. Preferably, the content is made 0.02% or less. The lower limit includes 0%, but from the viewpoint of reliably obtaining the effect of addition, 0.005% or more is preferable.

Nb: 0.1% or less

20 **[0030]** Nb is an element improving the hardenability. Further, a nitride of Nb acts as pinning particles, so Nb is an element which contributes to control of the transformation time and grain size at the time of heat treatment. If over 0.1%, the transformation finish time becomes longer, so the content is made 0.1% or less. Preferably, the content is made 0.07% or less. The lower limit includes 0%, but from the viewpoint of reliably obtaining the effect of addition, 0.005% or more is preferable.

25 Al: 0.1% or less

30 **[0031]** Al is an element effective as a deoxidizing element. If over 0.1%, hard inclusions are formed and the wire drawing ability falls, so the content is made 0.1% or less. Preferably, the content is made 0.07% or less. The lower limit includes 0%, but from the viewpoint of reliably obtaining the effect of addition, 0.02% or more is preferable.

Ca: 0.05% or less

35 **[0032]** Ca is a deoxidizing element. Further, it is an element effective for controlling the form of inclusions in the steel. If over 0.05%, coarse inclusions are formed, so the upper limit is made 0.05% or less. Preferably, the content is made 0.02% or less. The lower limit includes 0%, but from the viewpoint of reliably obtaining the effect of addition, 0.001% or more is preferable.

40 B: 0.005% or less

45 **[0033]** B is an element which segregates at the grain boundaries in a state of the solid solution B and suppresses the formation of ferrite. If over 0.005%, $M_{23}(C, B)_6$ precipitates at the grain boundaries and the wire drawability falls, so the content is made 0.005% or less. Preferably, the content is made 0.002% or less. The lower limit includes 0%, but from the viewpoint of reliably obtaining the effect of addition, 0.0003% or more is preferable.

N: 0.005% or less

50 **[0034]** Nitrogen (N) bonds with the nitride-forming elements such as Al and Ti to form precipitates in the steel material, which act as pinning particles at the austenite grain boundaries. Further, N present as a solid solution element causes the reduction of area to drop at the time of a tensile test. Further, if the amount of N exceeds 0.005%, the austenite grain boundaries become finer, the targeted bainite structure becomes difficult to obtain, and the reduction of area of the wire rod falls, so the upper limit is made 0.005%.

[0035] Next, the microstructure of the wire rod of the present invention will be explained.

55 **[0036]** The microstructure of the wire rod of the present invention is characterized in that, in the wire rod cross-section, 80% or more in terms of area ratio is a bainite structure and the remainder is a nonbainite structure and in that a full width at half maximum of a (211) crystal face of a ferrite phase in the microstructure of the wire rod cross-section is 0.6° or less.

[0037] In order to increase the ratio of the bainite structure, it is necessary to suppress ferrite transformation and

pearlite transformation (both diffusion transformations) from the heated austenite state as much as possible and cool to predetermined temperature. However, if the wire diameter is thick and the wire has an alloy component with a low hardenability, it becomes difficult to create the microstructure. In actual manufacture, reducing the ratio of the nonbainite structure to 0% is difficult.

5 **[0038]** Therefore, the inventors researched seriously the range in which a nonbainite structure will not affect the strength of the wire rod as a whole or the wire after wire drawing. As a result, they discovered that if the nonbainite structure is less than 20%, there is no effect on the strength of the wire rod as a whole or the wire after wire drawing. Based on this discovery, they defined the ratio of the bainite structure in the wire rod cross-section as 80% or more.

10 **[0039]** The ratio of the bainite structure can be determined by taking a sample of the wire rod whose cross-section perpendicular to the length direction is used as an observed surface, polishing the observed surface, subjecting it to Nital etching, or Le Pera etching according to need, and observing the observed surface using an optical microscope or electron microscope, or X-ray diffraction. By binarizing the microstructural photograph obtained by the optical microscope or electron microscope to white and black, it is possible to analyze the image and determine the area ratio of bainite. Note that the structural fraction may be determined by photographing a 1/4 part in the thickness direction of a sample
15 obtained from an arbitrary position of the steel sheet by X1000 in a range of $300 \times 300 \mu\text{m}$, and measuring three or more such observed fields by the above method. The bainite structure and nonbainite structure may also be distinguished by analyzing the measurement data on crystal orientations of the electron diffraction patterns obtained using EBSD (electron backscatter diffraction) by the KAM method (kernel average misorientation).

20 **[0040]** A bainite structure is comprised of carbides of granular cementite and a ferrite phase. The ratio of the bainite structure of the wire rod of the present invention is substantially determined by the bainite transformation step comprised of heating and cooling after the later explained coiling step. Furthermore, by performing the later explained heat treatment step of heating the wire rod where the bainite transformation is finished, the inventors found that the full width at half maximum of the (211) crystal plane of the ferrite phase in the structure of the wire rod cross-section will fall and a wire rod having good wire drawing ability can be obtained in the case of the full width at half maximum being 0.6° or less.

25 **[0041]** Note that, "full width at half maximum" means a width of the angle at the position where the height is half of the peak height in the diffraction peak of a certain crystal plane measured by X-ray diffraction. The pearlite structure contains a lot of elastic strain, so the full width at half maximum becomes high at the stage of formation of pearlite. Even if heating, it would be more difficult to decrease the full width at half maximum of the pearlite structure compared with the bainite structure. For this reason, the higher the pearlite fraction, the higher the full width at half maximum, so this
30 is suitable as an indicator for evaluation of the formed structure.

[0042] The (211) crystal plane of the ferrite phase in the microstructure of the wire rod cross-section is closely related to the dispersed state of carbides of the granular cementite and the content of pearlite in the microstructure of the wire rod cross-section. Therefore, the full width at half maximum becomes a parameter for judging the magnitudes of the bainite fraction of the wire rod, the dispersed state of carbides of granular cementite in the bainite structure, and the
35 content of pearlite. In actuality, the full width at half maximum tends to decrease along with an increase of the bainite fraction. Further, the full width at half maximum tends to decrease along with the uniformity of the dispersed state of cementite, to increase along with an increase of the content of pearlite being the nonbainite structure, and to decrease along with the drop in strength of the wire rod.

[0043] Next, the mechanical properties of the wire rod of the present invention will be explained.

40 **[0044]** The wire rod of the present invention is characterized by having a tensile strength TS (MPa) and reduction of area RA (%) respectively satisfying the following formula (1) and the following formula (2):

$$TS \leq 580 + 700 \times [C] \quad \dots (1)$$

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$$RA \geq 100 - 46 \times [C] - 18 \times [Mn] - 10 \times [Cr] \quad \dots (2)$$

where, [C], [Mn], and [Cr] respectively indicate the mass% of C, Mn, and Cr.

50 **[0045]** The tensile strength TS and reduction of area RA of the bainite wire rod depend on the average distance between cementite particles, the dislocation density, and the block particle size. In particular, in the wire rod of the present invention, they depend on the amount of carbon corresponding to the cementite fraction. The inventors investigated the relationship between the tensile strength TS and the amount of carbon ([C]) in the specific ranges of the ratio of the bainite structure and full width at half maximum of the ferrite phases. Further, the inventors investigated the
55 relationship of the reduction of area RA and "100-46×[C]-18×[Mn]-10×[Cr]".

[0046] "100-46×[C]-18×[Mn]-10×[Cr]" is an indicator evaluating the overall influence, and the indicator is obtained by multiplying the amounts of typical elements obstructing drawing by a coefficient of influence. By defining the lower

limit of this indicator, it is possible to obtain the mechanical properties of the wire rod of the present invention.

[0047] FIG. 1 shows the results of investigation of the relationship between the tensile strength TS and the amount of carbon ([C]). It will be understood that the tensile strength satisfies the above formula (1). The inventors discovered that the reduction of area RA is good if satisfying the above formula (2).

[0048] The hardness distribution in the cross-section also influences the wire drawing characteristics. The inventors discovered that by making the standard deviation of the distribution of hardness in the wire rod cross-section a Vickers hardness (Hv) of less than 6, a wire rod with good wire drawing characteristics is obtained.

[0049] Next, the method for production of the wire rod of the present invention will be explained.

[0050] The method for production of the wire rod of the present invention is characterized by hot rolling a billet of the chemical composition of the wire rod of the present invention into a wire rod, then winding it into a coil at 850 to 1050°C, next immersing it in 300 to 475°C molten salt or molten lead, completing the bainite transformation to obtain a bainite fraction of 80% or more, then immersing it in 550 to 650°C molten salt or molten lead for 15 seconds or more.

[0051] After hot rolling the billet of the chemical composition of the wire rod of the present invention into a wire rod, the wire rod temperature of the time of winding the wire rod up into a coil is important in the adjustment of austenite grain size. The coiling temperature of a wire rod changes according to the hardenability of the type of steel. However, if over 1050°C, the terminal treatment of the wire rod becomes physically difficult, so the temperature is made 1050°C or less. Preferably, it is 1000°C or less.

[0052] On the other hand, if the coiling temperature is less than 850°C, the austenite grain size becomes finer, the hardenability falls, and dual-phase decarburization of the surface layer part proceeds, so the temperature is made 850°C or more. Preferably, it is 900°C or more.

[0053] Further, another method for production of the wire rod of the present invention is characterized by heating a wire rod of a chemical composition of the present invention to 850°C or more, then immersing it in 300 to 475°C sand, molten salt, or molten lead for patenting to obtain 80% or more of a bainite structure in the cross-section of the wire rod, then using sand, molten salt, molten lead, or resistance heating or induction heating to heat it at 550 to 650°C for 1 second or more.

[0054] When heating the once cooled wire rod to cause bainite transformation, the heating temperature influences the hardenability of the steel material. If the heating temperature is less than 850°C, the austenite grain size becomes finer, the hardenability falls, the bainite fraction does not rise, and dual-phase decarburization of the surface layer part proceeds, so the temperature is made 850°C or more. Preferably, the temperature is 900°C or more.

[0055] To control the grains pinning the austenite grains, the heating temperature is set in accordance with the amount of the alloy elements, so the upper limit of the heating temperature is not particularly set, but from the viewpoint of economy, 1150°C or less is preferable. More preferably, the temperature is 1100°C or less.

[0056] The temperature of the sand, molten salt, or molten lead where the wire rods obtained by hot rolling the billet or the wire rods after reheating the once cooled wire rods is immersed (that is, cooling medium temperature) influences the bainite transformation temperature and cooling speed of the wire rods. If the cooling medium temperature exceeds 475°C, the cooling speed decreases and pearlite transformation occurs and conversion to bainite in the entire cross-section of the wire rod becomes difficult, so the temperature is made 475°C or less. Preferably, it is 450°C or less.

[0057] On the other hand, if the cooling medium temperature is less than 300°C, the bainite transformation becomes long in time, so the temperature is 300°C or more. Preferably, the temperature is 350°C or more.

[0058] The present invention can reheat a once cooled wire rod to 850°C or more, then hold the wire rod at 300 to 475°C in temperature range to make the bainite transformation of the wire rod structure progress and make the bainite structure of the wire rod uniform. This is because at that amount of carbon, the bainite structure is mainly produced at about 300°C to about 500°C in temperature, but the size of the bainite structure is affected by the temperature at the time of formation of the bainite structure. By holding the wire rod at 300 to 475°C in temperature range until the bainite transformation is completed, the bainite structure of the wire rod is made uniform. However, holding the temperature of the wire rod for a long period of time in the above-mentioned temperature range is not preferable from the viewpoint of the manufacturing cost. On the other hand, if heating the wire rod before the completion of the bainite transformation to over 475°C and holding the wire rod for a time equal to or longer than the predetermined time, the bainite transformation is completed. However, the bainite structure becomes uneven and the hardness distribution of the wire rod cross-section becomes uneven, so this is not preferable. Therefore, in the present invention, the wire rod is held at 300 to 475°C in temperature range until 80% or more of the structure in the wire rod cross-section becomes a bainite structure, then is heated at 550 to 650°C for 1 second or more as explained below.

[0059] Furthermore, the holding time until the bainite transformation is completed or the holding time until the bainite fraction becomes 80% or more may be determined in advance by predetermined experiments. For example, it is possible to investigate in advance the correspondence relationships among the compositions of wire rods, the holding time for immersion in molten salt or molten lead or the holding time for patenting, and the temperature and bainite fraction at the time of the immersion in the molten salt or the molten lead or at the time of patenting and determine the above-mentioned holding time based on the results of the above-mentioned investigation. In this case, the extent of the bainite transformation

has to be judged strictly corresponding to the actual measured values. Further, even in an untested method for production, it is possible to use the relationship between known manufacturing conditions close to the conditions of the untested method and the ratios of the bainite structure at those known manufacturing conditions as the basis for interpolation or extrapolation to forecast the ratio of the bainite structure of the wire rod produced by the untested method for production and determine the holding time. Alternatively, a test piece is prepared under the same manufacturing conditions as the manufacturing conditions which are to be attempted, the production of the wire rod may proceed while measuring the ratio of the bainite structure in the middle of the process of production of the wire rod.

[0060] A heat treatment step is performed for heating the wire rod after the completion of the bainite transformation. The heating temperature in this heat treatment step influences the recovery and softening of the bainite wire. If the heating temperature is less than 550°C, a sufficient softening effect is not obtained, so the heating temperature is made 550°C or more. Preferably, it is made 570°C or more. If over 650°C, Ostwald growth of the cementite progresses and the ductility of the wire rod decreases, so the temperature is made 650°C. Preferably, it is made 630°C or less.

[0061] The heating time after completion of the bainite transformation is adjusted according to the heating temperature, but is made 1 second or more so as to cause softening of bainite to progress. If the heating time becomes too long, Ostwald growth of the cementite progresses and the ductility decreases, but the time can be suitably adjusted in the range of the heating temperature, so no upper limit is particularly set. Further, the time until reaching the above heating temperature or the speed of temperature rise until reaching the above heating temperature is not particularly limited.

[0062] Note that, the heating may be performed not only by immersion in sand, molten salt, or molten lead, which is heated at a predetermined temperature, but also by resistance heating or induction heating.

[0063] Next, examples of the present invention will be explained. The conditions in the examples are just examples of conditions employed for confirming the feasibility and effects of the present invention. The present invention is not limited to these examples of conditions. The present invention can employ various conditions so long as not deviating from the gist of the present invention and so long as achieving the object of the present invention.

Examples

[0064] Wire rods of the chemical compositions A to O shown in Table 1 were held at the predetermined temperatures for the predetermined times shown in the "cooling conditions" shown in Table 2-1 to complete the bainite transformation. The wire rods after the completion of the bainite transformation were respectively heated until the predetermined temperatures shown in the "heat treatment conditions after completion of bainite transformation" and held at those predetermined temperatures for predetermined times. The results of measurement of the tensile strength TS (MPa) and reduction of area (%) of each of the heat treated wire rods, the results of measurement of the ratio of bainite structure and full width at half maximum of the ferrite phase in the bainite structure, and the distribution of hardness of the wire rod cross-section are shown in Table 2-2. Note that, the bainite transformation time is suitably changed with an upper limit of 300 seconds when directly heat treating the hot rolled wire rods and is suitably changed with an upper limit of 1800 seconds when patenting the reheated wire rods.

[0065] Further, for production of Invention Examples 1, 2, 6 to 8, 10, 12, and 13 and Comparative Example 1 to 6, wire rods obtained by hot rolling the billets of the chemical compositions shown in Table 1 under the conditions shown in Table 2-1 were used. Further, the wire rods of Invention Examples 3 to 5, 9, 11 and Comparative Example 7 were produced by the method for production including the steps of producing the wire rods of the chemical compositions shown in Table 1, cooling the wire rods once and reheating the wire rods by the heating temperatures shown in Table 2-1.

[0066] The composition of the steel type K in Table 1 corresponds to the composition of the steel wire of PLT 3. A wire rod having this composition was held at the predetermined temperature for the predetermined time of the "cooling conditions" of Table 2-1 to thereby cause progression of the bainite transformation of the wire rod of Comparative Example 6 before the bainite transformation was finished. Next, the wire rod of Comparative Example 7 was heated until the predetermined temperature shown in the "heat treatment conditions after completion of bainite transformation" and held at that predetermined temperature for a predetermined time as heat treatment to thereby finish bainite transformation.

[0067] For measurement of the ratio of bainite structure, electron backscatter diffraction (EBSD) was used. A region of 300 μm × 180 μm or more at the center part of the wire rod was measured. Based on the kernel average misorientation (KAM) method, the region where no crystal rotation occurred was defined as the bainite structure. The bainite fraction was thus calculated.

[0068] For the full width at half maximum of the ferrite phase, an X-ray diffraction apparatus was used. For the source of the X-rays, a Cr tubular lamp was used. The measurement surface was made the (211) plane. The time when a maximum count reached 3000 or more was measured. The full width at half maximum of that maximum count was made the measured value.

[0069] Further, the inventors investigated in advance the correspondence between manufacturing conditions such as compositions of the types of steel and heat treatment and the ratio of bainite structure for the wire rods of Invention

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Examples 1 to 13 and Comparative Example 1 to 7. Based on the results of their investigations, the extent of progression of bainite transformation in the microstructure of each of the wire rods was judged, and the start and end of the bainite transformation of each of the wire rods of Invention Examples 1 to 13 and Comparative Examples 1 to 7 were judged. **[0070]** For the distribution of hardness at the wire rod cross-section, a Vickers hardness tester was used to strike the cross-section in the longitudinal direction of the obtained structure at 100 points by a load of 1 kgf. The standard deviation was defined as the fluctuation in measured hardness.

Table 1

	Composition of wire rod (wt%)													
Steel type	C	Si	Mn	Cr	Ni	Cu	V	Mo	Ti	Nb	Al	Ca	B	N
A	0.70	0.20	0.40	-	0.10	-	-	-	-	0.02	-	0.01	-	0.0020
B	0.82	0.20	0.40	-	-	-	-	-	-	-	-	-	-	0.0035
C	0.82	1.80	0.40	-	-	-	-	-	-	-	0.03	-	-	0.0035
D	0.82	0.20	1.50	-	-	-	-	-	-	-	0.03	-	-	0.0029
E	0.82	0.20	0.40	0.08	-	0.05	-	-	-	-	-	-	-	0.0033
F	0.82	0.20	0.40	-	-	-	-	0.07	-	-	-	-	0.0005	0.0034
G	0.82	0.20	0.70	0.01	-	-	0.03	-	-	-	0.03	-	-	0.0026
H	0.82	0.20	0.70	-	-	-	-	-	-	-	0.03	-	-	0.0040
I	0.87	0.90	0.70	-	-	-	-	-	0.014	-	-	-	0.001	0.0033
J	0.92	0.20	0.40	0.20	-	-	-	-	-	-	-	-	-	0.0035
K	0.92	0.20	0.40	-	-	-	-	-	0.02	-	-	-	-	0.0060
L	1.00	1.20	0.40	0.25	-	-	-	-	-	-	0.03	-	-	0.0028
M	1.00	0.20	0.40	0.20	-	-	-	-	-	-	-	0.01	-	0.0035
N	1.17	0.20	0.40	0.20	-	-	-	-	-	-	-	-	-	0.0030
O	1.27	0.20	0.40	-	-	-	-	-	-	-	-	-	-	0.0032

(In the table, "-" indicates amount of addition of corresponding element to steel material is 0 wt%)

Table 2-1

Invention example/ Comparative example	Steel type	Wiresize (mm)	Heat treatment	Temperature condition before cooling		Cooling condition			Heat treatment condition after completion of bainite transformation		
				Coiling temp. (°C)	Heating temp. (°C)	Cooling medium	Temp. (°C)	Holding time (sec)	Cooling medium or heating method	Temp. (°C)	Time (sec)
Inv. Ex. 1	A	5.5	Direct	980	-	Salt	400	80	Salt	550	60
Comp. Ex. 1	A	5.5	Direct	720	-	Salt	400	80	Salt	550	60
Inv. Ex. 2	B	4	Direct	980	-	Salt	400	300	Salt	550	60
Inv. Ex. 3	B	5.5	Reheating	-	950	Lead	350	1200	resistance heating	600	15
Comp. Ex. 2	C	5.5	Direct	1000	-	Salt	425	40	Salt	550	60
Comp. Ex. 3	D	5.5	Direct	980	-	Salt	425	40	Salt	550	60
Comp. Ex. 4	E	5.5	Direct	980	-	Salt	500	40	Salt	575	60
Inv. Ex. 4	E	5.5	Reheating	-	980	Salt	425	80	Induction heating	650	3
Inv. Ex. 5	E	7	Reheating	-	1000	Lead	400	120	Lead	550	300
Inv. Ex. 6	F	5.5	Direct	980	-	Salt	425	40	Salt	575	60
Inv. Ex. 7	G	5.5	Direct	980	-	Salt	425	80	Lead	600	300
Inv. Ex. 8	H	5.5	Direct	980	-	Salt	425	40	Salt	550	60
Inv. Ex. 9	I	5.5	Reheating	-	950	Salt	425	300	Salt	550	60
Inv. Ex. 10	J	5.5	Direct	980	-	Salt	425	40	Salt	550	60
Comp. Ex. 5	J	5.5	Direct	980	-	Salt	425	40	-	-	-
Comp. Ex. 6	K	5.5	Direct	800	-	Salt	400	5	Salt	550	300
Inv. Ex. 11	L	5.5	Reheating	-	950	Salt	425	300	Salt	550	60
Inv. Ex. 12	M	5.5	Direct	980	-	Salt	425	40	Salt	575	60
Inv. Ex. 13	N	5.5	Direct	980	-	Salt	425	40	Salt	550	60
Comp. Ex. 7	O	5.5	Reheating	-	980	Lead	425	80	Lead	550	60

Table 2-2

Invention example / Comparative example	Steel type	Wire size (mm)	TS (MPa)	RA (%)	Hardness distribution (Hv)	Ratio of bainite structure (%)	full width at half maximum (°)	Formula (1) right side	Formula (2) right side
								TS (MPa)	RA (%)
Inv. Ex. 1	A	5.5	1086	60	4.9	92	0.563	1104	60
Comp. Ex. 1	A	5.5	1111	60	7.3	30	0.518	1104	60
Inv. Ex. 2	B	4	1160	58	5.1	96	0.564	1174	55
Inv. Ex. 3	B	5.5	1149	56	4.5	88	0.523	1174	55
Comp. Ex. 2	C	5.5	1235	40	10.2	25	0.545	1174	55
Comp. Ex. 3	D	5.5	1240	23	6.5	45	0.680	1174	35
Comp. Ex. 4	E	5.5	1128	54	8.1	15	0.520	1174	54
Inv. Ex. 4	E	5.5	1139	56	3.9	93	0.540	1174	54
Inv. Ex. 5	E	7	1104	56	4.1	85	0.509	1174	54
Inv. Ex. 6	F	5.5	1125	57	4.5	92	0.541	1174	55
Inv. Ex. 7	G	5.5	1030	52	3.3	87	0.493	1174	50
Inv. Ex. 8	H	5.5	1158	51	4.2	89	0.549	1174	50
Inv. Ex. 9	I	5.5	1198	49	4.5	85	0.542	1209	47
Inv. Ex. 10	J	5.5	1241	55	4.5	90	0.546	1244	48
Comp. Ex. 5	J	5.5	1268	56	5.2	91	0.693	1244	48
Comp. Ex. 6	K	5.5	1320	44	8.5	28	0.533	1244	54
Inv. Ex. 11	L	5.5	1283	46	4.8	82	0.549	1300	44
Inv. Ex. 12	M	5.5	1247	45	4.4	95	0.545	1300	45
Inv. Ex. 13	N	5.5	1382	39	4.7	92	0.543	1419	37
Comp. Ex. 7	O	5.5	1444	21	5.5	88	0.531	1489	34

[0071] Invention Examples 1 to 13 are working examples of the present invention. As shown in Table 2-2, bainite wire rods excellent in wire drawing characteristics are obtained.

[0072] In Comparative Example 1, the coiling temperature after rolling the billet was low. The ferrite transformation proceeded from the time of coiling to the time of cooling, so the targeted ratio of bainite structure was not obtained. Further, the tensile strength TS also did not satisfy formula (1).

[0073] In Comparative Examples 2 and 3, the elements improving the hardenability, that is, Si and Mn, were respectively over the prescribed ranges and the hardenability became too high, so the transformation was not completed by the first stage of cooling. In Comparative Example 4, the temperature in the first stage of cooling exceeded the prescribed range, so the cooling became slower and a large amount of pearlite was formed. As a result, the targeted ratio of bainite structure could not be obtained.

[0074] In Comparative Example 5, the heating in the second stage of cooling was not performed, so the full width at half maximum exceeded the prescribed value and the tensile strength TS did not satisfy formula (1). In Comparative Example 6, C exceeded the prescribed range, cementite was formed during the cooling from austenite, and the reduction of area RA did not satisfy formula (2).

[0075] In Comparative Example 6, the wire rod was heated before the completion of the bainite transformation, so the bainite structure became uneven and the hardness distribution in the wire rod cross-section was uneven. For this reason, in Comparative Example 6, the reduction of area RA did not satisfy formula (2), the wire rod fell in ductility, and the wire drawing characteristics became lower.

Industrial Applicability

[0076] As explained above, according to the present invention, it is possible to provide a wire rod excellent in wire drawing characteristics based on findings regarding the softening mechanism of bainite and the ratio of structures enabling reduction of the work hardening rate. Accordingly, the present invention has a high applicability in the wire rod producing industry.

Claims

1. A wire rod excellent in wire drawing ability having a chemical composition comprising, by mass%, C: 0.7 to 1.2%, Si: 0.1 to 1.5%, Mn: 1.0% or less, N: 0.005% or less, and a balance of Fe and unavoidable impurities, wherein 80% or more of a microstructure is a bainite structure and a remaining microstructure is a nonbainite structure in a cross-section of the wire rod, wherein a full width at half maximum of a (211) crystal face of a ferrite phase in the microstructure of said wire rod cross-section is 0.6° or less, wherein a tensile strength TS (MPa) and reduction of area RA (%) respectively satisfy a following formula (1) and a following formula (2), and wherein a standard deviation of hardness distribution of Vickers hardness (Hv) in the cross-section is less than 6.

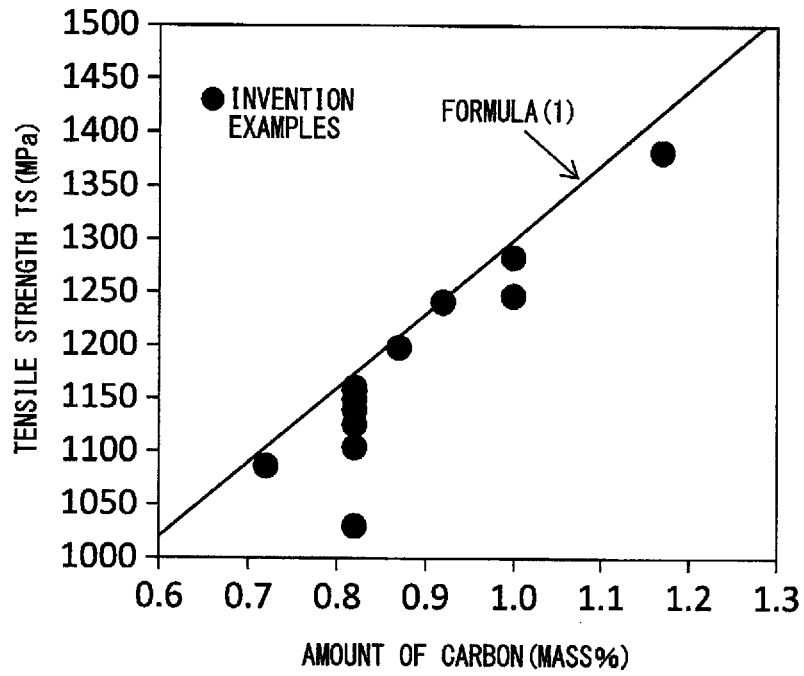
$$TS \leq 580 + 700 \times [C] \quad \dots (1)$$

$$RA \geq 100 - 46 \times [C] - 18 \times [Mn] - 10 \times [Cr] \quad \dots (2)$$

where, [C], [Mn], and [Cr] respectively indicate the mass% of C, Mn, and Cr.

2. The wire rod excellent in wire drawing ability according to claim 1 wherein said chemical composition further contains, by mass%, one or more of Cr: 1.0% or less, Ni: 1.0% or less, Cu: 0.1% or less, V: 0.1% or less, Mo: 0.5% or less, Ti: 0.05% or less, Nb: 0.1% or less, Al: 0.1% or less, Ca: 0.05% or less, and B: 0.005% or less.
3. A method for production of a wire rod excellent in wire drawing ability according to claim 1 or 2 comprising hot rolling a billet of a chemical composition according to claim 1 or 2 into a wire rod, then winding the wire rod into a coil at 850 to 1050°C, next immersing the wire rod in 300 to 475°C molten salt or molten lead and completing bainite transformation to obtain a bainite fraction of 80% or more, and then immersing the wire rod in 550 to 650°C molten salt or molten lead for 1 second or more.
4. A method for production of a wire rod excellent in wire drawing ability according to claim 1 or 2 comprising heating a wire rod of a chemical composition according to claim 1 or 2 to 850°C or more, then immersing the wire rod in 300 to 475°C sand, molten salt, or molten lead for patenting to obtain a bainite structure of 80% or more in a cross-section of the wire rod, and then using sand, molten salt, molten lead, or resistance heating or induction heating to heat the wire rod at 550 to 650°C for 1 second or more.

FIG. 1



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/056691

5	A. CLASSIFICATION OF SUBJECT MATTER C22C38/00(2006.01)i, C21D8/06(2006.01)i, C21D9/52(2006.01)i, C22C38/04 (2006.01)i, C22C38/54(2006.01)i	
	According to International Patent Classification (IPC) or to both national classification and IPC	
10	B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) C22C38/00-38/60	
15	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 1996-2015 Kokai Jitsuyo Shinan Koho 1971-2015 Toroku Jitsuyo Shinan Koho 1994-2015	
	Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)	
20	C. DOCUMENTS CONSIDERED TO BE RELEVANT	
	Category*	Citation of document, with indication, where appropriate, of the relevant passages
25	A	JP 7-258787 A (Nippon Steel Corp.), 09 October 1995 (09.10.1995), claims 1 to 3; table 2, invention methods b, d (Family: none)
30	A	JP 2002-241899 A (Kobe Steel, Ltd.), 28 August 2002 (28.08.2002), claims 1 to 7 (Family: none)
35	A	JP 8-3639 A (Nippon Steel Corp.), 09 January 1996 (09.01.1996), claims 1 to 6 (Family: none)
40	<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.	
45	* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "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
50	Date of the actual completion of the international search 12 May 2015 (12.05.15)	Date of mailing of the international search report 19 May 2015 (19.05.15)
55	Name and mailing address of the ISA/ Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Authorized officer Telephone No.

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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 7-268487 A (Nippon Steel Corp.), 17 October 1995 (17.10.1995), claims 1 to 7 (Family: none)	1-4
A	JP 5-117764 A (Nippon Steel Corp.), 14 May 1993 (14.05.1993), claim 1 (Family: none)	1-4

REFERENCES CITED IN THE DESCRIPTION

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- JP 6073501 A [0006]