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(54) STEEL WIRE FOR MECHANICAL STRUCTURAL PARTS

(57) An object of the present invention is to provide a steel wire for mechanical structural parts that is reduced in deformation resistance and improved in crack resistance during cold working, and thus exhibits excellent cold workability. The steel wire for mechanical structural parts of the present invention is a steel wire containing, in mass%, 0.3 to 0.6% of C, 0.05 to 0.5% of Si, 0.2 to 1.7% of Mn, more than 0% and 0.03% or less of P, 0.001 to 0.05% of S, 0.005 to 0.1% of Al, and 0 to 0.015% of N, the balance being iron and inevitable impurities, wherein steel of the steel wire has a metal structure formed of ferrite and cementite, and the number proportion of cementite particles present in ferrite grain boundaries is 40% or more based on the total number of cementite particles.

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Description

TECHNICAL FIELD

[0001] The present invention relates to a steel wire used as a material for mechanical structural parts. More specifically, the present invention relates to a steel wire for mechanical structural parts which, when being produced by spheroidizing annealing and subsequent cold working from a wire rod produced by temper rolling, is low in deformation resistance and good in crack resistance during cold working, and thus exhibits excellent cold workability. The term "wire rod" as used herein refers to a rolled wire rod, which is a wire-like steel material that has been hot-rolled and then cooled to room temperature. The term "steel wire" as used herein refers to a wire-like steel material which is obtained by subjecting a rolled wire rod to tempering treatment such as spheroidizing annealing.

BACKGROUND ART

[0002] In the production of various mechanical structural parts such as automobile parts and construction machinery parts, a hot-rolled wire rod made of carbon steel, alloy steel or the like is usually subjected to spheroidizing annealing for acquisition of cold workability. Then, the rolled wire rod after the spheroidizing annealing, that is, a steel wire, is subjected to cold working, and then to machining such as cutting to be formed into a predetermined shape. The steel wire is then subjected to quenching and tempering treatment for final adjustment of the strength, whereby a mechanical structural part is obtained.

[0003] In the cold working, lowering the deformation resistance of a steel wire may probably prolong the die life. Further, improving the crack resistance of a steel wire may probably improve the yield of various parts.

[0004] So far, various methods have been proposed as techniques for improving the cold workability of a steel wire. As such a technique, for example, Patent Document 1 discloses a technique of "a steel wire that has a metal structure that is effectively formed from ferrite grains and carbide spheres where the average diameter of the ferrite grains is greater than or equal to 15 μm, the average diameter of the carbide spheres is less than or equal to 0.8 μm, the largest diameter of the carbide spheres is less than or equal to 4.0 μm, the number of carbide spheres per 1 mm^2 is $0.5 \times 10^6 \times$ C% to $5.0 \times 10^6 \times$ C%, and amongst the carbide spheres, the greatest separation between carbide spheres with a diameter of greater than or equal to 0.1 μm is less than or equal to 10 μm".

[0005] Further, Patent Document 2 discloses a technique of "a steel wire in which the steel has a metal structure including cementite and ferrite, the total area rate of cementite and ferrite to the whole structure being 95 area% or more, the aspect ratio of 90% or more of the cementite being 3 or less, the average center of gravity distance of the cementite being 1.5 μm or more, the average crystal grain size of the ferrite being 5 to 20 μm".

[0006] Patent Document 2 discloses, as a means for obtaining such metal structure, that the following annealing treatment is performed twice or more: heating the steel to a temperature range of point A1 to (point A1 + 50°C), holding the steel in the temperature range of point A1 to (point A1 + 50°C) for 0 to 1 hour, and cooling the steel from the temperature range of point A1 to (point A1 + 50°C) to a temperature range of (point A1 - 100°C) to (point A1 - 30°C) at an average cooling rate of 10 to 200°C/h; and then the conditions for heating the steel to a temperature range of point A1 to (point A1 + 30°C), holding the steel in the temperature range of point A1 to (point A1 + 30°C), and cooling the steel are controlled as follows. That is, when the temperature reaches point A1 in heating and the steel is held in the temperature range of point A1 to (point A1 + 30°C) and then cooled, the temperature range residence time in the range of point A1 to (point A1 + 30°C) until the temperature reaches point A1 is controlled to 10 minutes to 2 hours, the steel is cooled in a cooling temperature range from the temperature range of point A1 to (point A1 + 30°C) to (point A1 - 100°C) to (point A1 - 20°C) at an average cooling rate of 10 to 100°C/h, and then the steel is held in the cooling temperature range for 10 minutes to 5 hours and further cooled.

[0007] Meanwhile, Patent Document 3 discloses a technique of "a steel wire having a structure in which the value obtained by dividing the standard deviation of distances between cementite particles by the average value of the distances between cementite particles is 0.50 or less". In this method, the cementite particles are distributed at substantially uniform spacings, and many cementite particles are present also in the ferrite grains.

PRIOR ART DOCUMENT

PATENT DOCUMENT

[0008]

Patent Document 1: WO2011/108459
Patent Document 2: JP 2012-140674 A

Patent Document 3: JP 2006-316291 A

SUMMARY OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0009] Although the techniques proposed so far are useful as techniques for providing a steel wire improved in cold workability in cold forging or the like, development of a technique for providing a steel wire further improved in cold workability is desired.

[0010] The present invention has been made under such circumstances, and it is an object of the present invention to provide a steel wire for mechanical structural parts that is reduced in deformation resistance and improved in crack resistance during cold working, and thus exhibits excellent cold workability.

MEANS FOR SOLVING THE PROBLEMS

[0011] A steel wire for mechanical structural parts of the present invention which achieves the above-mentioned object is a steel wire containing, in mass%, 0.3 to 0.6% of C, 0.05 to 0.5% of Si, 0.2 to 1.7% of Mn, more than 0% and 0.03% or less of P, 0.001 to 0.05% of S, 0.005 to 0.1% of Al, and 0 to 0.015% of N, the balance being iron and inevitable impurities, wherein steel of the steel wire has a metal structure formed of ferrite and cementite, and the number proportion of cementite particles present in ferrite grain boundaries is 40% or more based on the total number of cementite particles.

[0012] The steel wire for mechanical structural parts of the present invention preferably optionally contains, in mass%, at least one component selected from the group consisting of: more than 0% and 0.5% or less of Cr, more than 0% and 0.25% or less of Cu, more than 0% and 0.25% or less of Ni, more than 0% and 0.25% or less of Mo, and more than 0% and 0.01% or less of B.

[0013] In the steel wire for mechanical structural parts of the present invention, the average equivalent circle diameter of bcc (body-centerd cubic)-Fe crystal grains in the metal structure is preferably 30 μm or less.

EFFECTS OF THE INVENTION

[0014] The present invention can provide a steel wire for mechanical structural parts that realizes reduction in deformation resistance and improvement in crack resistance since the chemical component composition of the steel is appropriately adjusted, the metal structure of the steel is formed of ferrite and cementite, and the number proportion of cementite particles present in ferrite grain boundaries based on the total number of cementite particles satisfies a prescribed value. The steel wire for mechanical structural parts of the present invention exhibits excellent cold workability since it is reduced in deformation resistance and thus can suppress abrasion and destruction of a plastic working tool such as a die, and since it is also improved in crack resistance and thus can suppress the occurrence of cracks at the time of heading.

MODE FOR CARRYING OUT THE INVENTION

[0015] The inventors of the present invention made investigations from various angles in order to realize a steel wire that achieves both of reduction in deformation resistance and improvement in crack resistance during cold working. As a result, the inventors found that, during cold working, cementite in the ferrite grains increases deformation resistance and voids that cause cracks originate from cementite in the ferrite grains.

[0016] Cementite present in ferrite grain boundaries undergo less strain during cold working than cementite present in the grains does, and thus can reduce the deformation resistance and can be prevented from being the origin of voids. That is, the present inventors hit upon an idea that, in order to achieve both of reduction in deformation resistance and improvement in crack resistance, it is important to increase the number proportion of cementite particles present in ferrite grain boundaries based on the total number of cementite particles, that is, to reduce the number proportion of cementite particles present in the ferrite grains based on the total number of cementite particles.

[0017] In the techniques proposed so far, a method of controlling the ferrite grain size is known as a method of reducing the deformation resistance and improving the crack resistance. However, no technique has been proposed that focuses on cementite accumulated in grain boundaries.

[0018] In the following, requirements defined in the present invention will be described.

[0019] The metal structure of the steel wire for mechanical structural parts of the present invention (hereinafter sometimes simply referred to as "steel wire") is a so-called spheroidized structure and is formed of ferrite and cementite. The spheroidized structure is a metal structure that contributes to improvement in cold workability by reducing the deformation resistance of steel. The metal structure of the present invention may partially include a pearlite structure. In addition, the metal structure may include less than 3% in area rate of precipitates of AlN or the like as long as the cold workability is not largely adversely affected.

[0020] However, it is impossible to improve the cold workability by merely employing a metal structure formed of ferrite and cementite. From these viewpoints, it is necessary to appropriately control the number proportion of cementite particles present in ferrite grain boundaries based on the total number of cementite particles in this metal structure as described in detail below.

[0021] In the present specification, the number proportion of cementite particles present in ferrite grain boundaries (grain boundary cementite) based on the total number of cementite particles is sometimes referred to as "grain boundary cementite percentage". In addition, the number proportion of cementite particles present in ferrite grains (intragranular cementite) based on the total number of cementite particles is sometimes referred to as "intragranular cementite percentage". The "grain boundary cementite percentage" and "intragranular cementite percentage" are defined as follows.

[0022] In the microscopic observation of the metal structure, numbers of grain boundary cementite particles and intragranular cementite particles are measured in a predetermined field of view by a predetermined method.

[0023] The number of grain boundary cementite particles, the number of intragranular cementite particles, and the total number of cementite particles (total of number of grain boundary cementite particles and intragranular cementite particles) are defined as "Na", "Nb" and "Na + Nb", respectively. The grain boundary cementite percentage and intragranular cementite percentage can be determined as follows.

$$\text{Grain boundary cementite percentage (\%)} = \mathrm{Na}/(\mathrm{Na} + \mathrm{Nb}) \times 100$$

$$\text{Intragranular cementite percentage (\%)} = \mathrm{Nb}/(\mathrm{Na} + \mathrm{Nb}) \times 100$$

[0024] The number of cementite particles may be measured in one field of view or in a plurality of fields of view. In the case of measuring the number of cementite particles in a plurality of fields of view, the grain boundary cementite percentage and intragranular cementite percentage are respectively calculated using the total number of the numbers of grain boundary cementite particles and the total number of the numbers of intragranular cementite particles measured in the fields of view.

[0025] Details of the measurement method will be described later.

[0026] When the grain boundary cementite percentage decreases and the intragranular cementite percentage increases, the dislocation introduced into the ferrite grains during cold working is trapped in the intragranular cementite, causing an increase in dislocation and work hardening. As a result, deformation resistance increases and cold workability deteriorates. In addition, intragranular cementite is more likely to accumulate strain therearound during cold working than grain boundary cementite is. As a result, intragranular cementite tends to be the origin of cracks. From this point too, it is very effective to precipitate cementite on the ferrite grain boundaries in order to improve the cold workability.

[0027] From such a viewpoint, the number proportion of cementite particles present in ferrite grain boundaries (that is, the grain boundary cementite percentage) needs to be 40% or more based on the total number of cementite particles. By setting the grain boundary cementite percentage to 40% or more, it is possible to reduce the deformation resistance and suppress the occurrence of cracks originating from cementite.

[0028] The form of cementite as an object of measurement of the number of grain boundary cementite particles and the number of intragranular cementite particles is not particularly limited. For example, besides spherical cementite, rod-shaped cementite having a large aspect ratio and lamellar cementite forming a pearlite structure can be mentioned, and there is no limitation on the shape of cementite. The size of cementite particle as an object of measurement is not limited, and the criterion of size is determined according to the measurement method. In the method of measuring the grain boundary cementite percentage described later, the size of cementite particle that can be identified by an optical microscope at a magnification of 1000 times is the minimum size. More specifically, a cementite particle having an equivalent circle diameter of 0.3 μm or more is an object of measurement.

[0029] The lower limit of the grain boundary cementite percentage is preferably 45%, more preferably 50%. The higher the grain boundary cementite percentage is, the more effective the steel wire is in the reduction in deformation resistance and suppression of cracks, and the grain boundary cementite percentage is most preferably 100%. However, as will be described later, increase in the grain boundary cementite percentage is not easy from the viewpoint of production, and the current technique sometimes has disadvantages such as reduction in hot rolling temperature and/or prolongation of spheroidizing annealing. In the current technique, the grain boundary cementite percentage is preferably about 80% or less, more preferably 70% or less from the viewpoint of productivity.

[0030] In the steel wire of the present invention, the average equivalent circle diameter of bcc-Fe crystal grains in the metal structure is preferably 30 μm or less. When the average equivalent circle diameter of bcc-Fe crystal grains (hereinafter sometimes simply referred to as "bcc-Fe crystal grain size") is set to 30 μm or less, it is possible to improve the ductility and to further suppress the occurrence of cracks during cold working. A preferable upper limit of the bcc-Fe crystal grain size is 25 μm, and it is more preferably 20 μm. Although the size of the bcc-Fe crystal grains as an object of measurement is not limited, as with the cementite, the criterion of size is determined by the measurement method. In the measurement method described later, the size of the crystal grains that can be identified by an EBPS analyzer and a FE-SEM is the minimum size. More specifically, bcc-Fe crystal grains having an equivalent circle diameter of 1 μm or more are an object of measurement.

[0031] The structure whose bcc-Fe crystal grain size is to be controlled is bcc-Fe crystal grains surrounded by high-angle grain boundaries having an orientation difference larger than 15°. This is because low-angle grain boundaries having an orientation difference of 15° or less have only small influence on the cold workability. The above-mentioned "crystal orientation difference" is also referred to as "deviation angle" or "inclination angle", and the orientation difference may be measured by the EBSP method (Electron Backscattering Pattern method). In addition, bcc-Fe crystal grains surrounded by high-angle grain boundaries that are to be measured for the average grain size include not only proeutectoid ferrite but also ferrite included in the pearlite structure.

[0032] The present invention is directed to the steel wire for use as a material for mechanical structural parts. The steel wire for mechanical structural parts should have a usual chemical component composition, and contents of C, Si, Mn, P, S, A1 and N should each be preferably adjusted within an appropriate range. From these viewpoints, appropriate content ranges of these chemical components and reasons for such limitation are as follows. Incidentally, in the present specification, "%" in terms of chemical component composition means mass%.

C: 0.3 to 0.6%

[0033] C is an element effective for securing the strength of the steel, that is, the strength of the final product. In order that such an effect may be effectively exhibited, the C content needs to be 0.3% or more. The C content is preferably 0.32% or more, more preferably 0.34% or more. However, if C is excessively contained, the strength increases to deteriorate the cold workability, and thus the C content should be controlled to 0.6% or less. The C content is preferably 0.55% or less, more preferably 0.50% or less.

Si: 0.05 to 0.5%

[0034] Si is incorporated as a deoxidizing element and for the purpose of increasing the strength of the final product by solid solution hardening. In order that such an effect may be effectively exhibited, the Si content is determined to be 0.05% or more. The Si content is preferably 0.07% or more, more preferably 0.10% or more. On the other hand, if Si is excessively contained, the hardness excessively increases to deteriorate the cold workability. Therefore, the Si content is determined to be 0.5% or less. The Si content is preferably 0.45% or less, more preferably 0.40% or less.

Mn: 0.2 to 1.7%

[0035] Mn is an element effective for increasing the strength of the final product through improvement in hardenability. In order that such an effect may be effectively exhibited, the Mn content is determined to be 0.2% or more. The Mn content is preferably 0.3% or more, more preferably 0.4% or more. On the other hand, if Mn is excessively contained, the hardness increases to deteriorate the cold workability. Therefore, the Mn content is determined to be 1.7% or less. The Mn content is preferably 1.5% or less, more preferably 1.3% or less.

P: more than 0% and 0.03% or less

[0036] P is an element inevitably contained in steel, and causes grain boundary segregation in steel to deteriorate the ductility. Therefore, the P content is determined to be 0.03% or less. The P content is preferably 0.02% or less, more preferably 0.017% or less, particularly preferably 0.01% or less. The lower the P content is, the more preferable it is, but there are cases where about 0.001% of P remains due to limitations in the production process or the like.

S: 0.001 to 0.05%

[0037] S is an element inevitably contained in steel and exists as MnS in steel. Since S deteriorates the ductility, it is an element harmful to cold workability. Therefore, the S content is determined to be 0.05% or less. The S content is preferably 0.04% or less, more preferably 0.03% or less. However, since S has an action of improving machinability, S is incorporated in an amount of 0.001% or more. The S content is preferably 0.002% or more, more preferably 0.003% or more.

Al: 0.005 to 0.1%

[0038] Al is effective as a deoxidizing element and is also effective for fixing dissolved N present in steel as AlN. In order that Al may exhibit these effects effectively, the Al content is determined to be 0.005% or more. The Al content is preferably 0.008% or more, more preferably 0.010% or more. However, when the Al content is excessive, Al_2O_3 is excessively formed to deteriorate the cold workability. Therefore, the Al content is determined to be 0.1% or less. The Al content is preferably 0.090% or less, more preferably 0.080% or less.

N: 0 to 0.015%

[0039] N is an element inevitably contained in steel. If dissolved N is contained in steel, the hardness increases and the ductility deteriorates due to strain aging, whereby the cold workability is deteriorated. Therefore, the N content is determined to be 0.015% or less. The N content is preferably 0.013% or less, more preferably 0.010% or less. The lower the N content is, the more preferable it is, but there are cases where about 0.001% of N remains due to limitations in the production process or the like.

[0040] The basic components of the steel wire of the present invention are as described above, and the balance is substantially iron. Incidentally, "substantially iron" means that the balance may include not only iron but also trace components (for example, Sb and Zn) which do not impair the properties of the present invention, and inevitable impurities other than P, S and N (for example, O and H). Further, in the present invention, the steel wire may optionally contain the following optional elements, and the properties of the steel wire are further improved depending on the contained components:

> at least one component selected from the group consisting of more than 0% and 0.5% or less of Cr, more than 0% and 0.25% or less of Cu, more than 0% and 0.25% or less of Ni, more than 0% and 0.25% or less of Mo, and more than 0% and 0.01% or less of B
> All of Cr, Cu, Ni, Mo and B are elements effective for increasing the strength of the final product by improving the hardenability of the steel material, and are optionally incorporated alone or in combination of two or more. Such an effect increases as the contents of these elements increase. A preferable Cr content for the above-mentioned effect to be effectively exhibited is 0.015% or more, and it is more preferably 0.020% or more. The contents of Cu, Ni and Mo are each preferably 0.02% or more, more preferably 0.05% or more. The B content is preferably 0.0003% or more, more preferably 0.0005% or more.

[0041] However, when the contents of Cr, Cu, Ni, Mo and B are excessive, the strength increases too much to deteriorate the cold workability. Therefore, the Cr content is preferably 0.5% or less, the contents of Cu, Ni and Mo are each preferably 0.25% or less, and the B content is preferably 0.01% or less. A more preferable Cr content is 0.45% or less, and it is more preferably 0.40% or less. More preferable upper limits of contents of Cu, Ni and Mo are each 0.22%, and they are more preferably 0.20%. A more preferable upper limit of the B content is 0.007%, and it is more preferably 0.005%.

[0042] In the steel wire of the present invention, the structural form after spheroidizing annealing is defined. In order to obtain such a structural form, it is preferable to appropriately control the spheroidizing annealing conditions described later. It is to be noted that in order to secure the above-mentioned structural form, it is more preferable to further appropriately control the conditions at the stage of producing the rolled wire rod to realize a structural form of the rolled wire rod by which grain boundary cementite is likely to precipitate during spheroidizing annealing.

[0043] At the stage of producing the rolled wire rod, it is preferable to adjust the finish rolling temperature at the time of hot rolling the steel satisfying the above-mentioned component composition, and to appropriately adjust the cooling rate and the temperature range in the subsequent three-staged cooling. By producing the rolled wire rod under such conditions, the structure before the spheroidizing annealing includes pearlite and ferrite as main phases and has a bcc-Fe crystal grain size within a predetermined range, the proeutectoid ferrite crystal grains are equiaxed, and the spacing at the narrowest part of pearlite can be made not more than a predetermined value. Subjecting such a structure to spheroidizing annealing under the conditions described later makes it easy to obtain a steel wire in which grain boundary cementite is sufficiently precipitated. Preferable specific production conditions for the rolled wire rod are as follows: the finish rolling is performed at 800°C or more and 1050°C or less, and then the first cooling at an average cooling rate of 7°C/s or more, the second cooling at an average cooling rate of 1°C/s or more and 5°C/s or less, and the third cooling at an average cooling rate of 5°C/s or more that is higher than in the second cooling are performed in this order. The finish temperature of the first cooling and the start temperature of the second cooling are preferably in the range of 700 to 750°C. The finish temperature of the second cooling and the start temperature of the third cooling are preferably in the range of 600 to 650°C. The finish temperature of the third cooling is preferably 400°C or less. The finish rolling temperature and the first to third cooling will be described in detail.

(a) Finish rolling temperature: 800°C or more and 1050°C or less

[0044] In order to make the bcc-Fe crystal grain size of the structure before the spheroidizing annealing small, for example, 15 μm or less, it is preferable to appropriately control the finish rolling temperature. When the finish rolling temperature exceeds 1050°C, it becomes difficult to make the bcc-Fe crystal grain size small. However, when the finish rolling temperature is less than 800°C, the bcc-Fe crystal grain size becomes too small, for example, less than 5 μm, and softening becomes difficult. Thus, it is preferable to set the finish rolling temperature to 800°C or more. A more preferable lower limit of the finish rolling temperature is 850°C, and it is even more preferably 900°C or more. A more preferable upper limit of the finish rolling temperature is 1000°C, and it is even more preferably 950°C.

(b) First cooling

[0045] The first cooling starts at a finish rolling temperature of 800°C or more and 1050°C or less and finishes in a temperature range of 700 to 750°C. In this first cooling, if the cooling rate is low, bcc-Fe crystal grains of the structure before the spheroidizing annealing may be coarsened to increase the bcc-Fe crystal grain size. Therefore, it is preferable to set the average cooling rate in the first cooling to 7°C/s or more. The average cooling rate in the first cooling is more preferably 10°C/s or more, even more preferably 20°C/s or more. Although the upper limit of the average cooling rate in the first cooling is not particularly limited, it is practically preferably 200°C/s or less. In the first cooling, cooling may be performed at a variable cooling rate as long as the average cooling rate is 7°C/s or more.

(c) Second cooling

[0046] The second cooling starts in a temperature range of 700 to 750°C and finishes in a temperature range of 600 to 650°C. In order that the proeutectoid ferrite crystal grains may be equiaxed, that is, in order to make the average aspect ratio of the proeutectoid ferrite crystal grains small, for example, 3.0 or less, the steel is preferably gradually cooled at an average cooling rate of 5°C/s or less in the second cooling. The upper limit of the average cooling rate in the second cooling is more preferably 4°C/s, even more preferably 3.5°C/s or less. On the other hand, if the average cooling rate in the second cooling is too low, the bcc-Fe crystal grains may be coarsened to increase the bcc-Fe crystal grain size too much. Therefore, the average cooling rate in the second cooling is preferably 1°C/s or more. A more preferable lower limit of the average cooling rate in the second cooling is 2°C/s, and it is even more preferably 2.5°C/s. In the second cooling, cooling may be performed at a variable cooling rate as long as the average cooling rate is 1°C/s or more and 5°C/s or less.

(d) Third cooling

[0047] The third cooling starts in a temperature range of 600 to 650°C and finishes at 400°C or less. In this third cooling, the average lamellar spacing of pearlite should be made as narrow as possible to make it easy to dissolve cementite, leaving no spherical cementite nuclei in the grains. As a result, the grain boundary cementite percentage is increased by subsequently performing appropriate spheroidizing annealing treatment. In order to narrow the average lamellar spacing of pearlite to, for example, 0.20 μm or less, it is preferable to cool the steel in the third cooling at an average cooling rate of 5°C/s or more that is higher than in the second cooling. Cooling slower than 5°C/s makes it difficult to reduce the average lamellar spacing of pearlite. The average cooling rate in the third cooling is more preferably 10°C/s or more, even more preferably 20°C/s or more.

[0048] Although the upper limit of the average cooling rate in the third cooling is not particularly limited, it is practically preferably 200°C/s or less. In the third cooling, cooling may be performed at a variable cooling rate as long as the average cooling rate is 5°C/s or more. Although the lower limit of the finish temperature of the third cooling is not particularly limited, it is preferably 200°C, for example. After the third cooling, the steel may be subjected to ordinary cooling, for example, left standing still to cool to room temperature.

[0049] After cooling to room temperature, wire drawing may be optionally carried out at room temperature, and the reduction of area in the wire drawing may be set to 30% or less, for example. When the steel wire is drawn, carbides in the steel are destroyed and agglomeration of the carbides can be accelerated by the subsequent spheroidizing annealing. Thus, wire drawing is effective for shortening the soaking time of the spheroidizing annealing. However, when the reduction of area in wire drawing exceeds 30%, the strength after annealing may increase to deteriorate the cold workability. Therefore, the reduction of area in wire drawing is preferably 30% or less. Although the lower limit of the reduction of area is not particularly limited, it is preferably 2% or more to obtain the above-mentioned effect.

[0050] In the rolled wire rod produced under the preferable conditions as described above, pearlite in the structure is transformed into austenite, and then into ferrite and cementite by the subsequent spheroidizing annealing treatment. In this process, when the original pearlite size is reduced, that is, when the grain growth of the metal structure is suppressed, intragranular precipitation of cementite is reduced and grain boundary cementite is likely to precipitate.

[0051] As such spheroidizing annealing conditions, the following conditions as in SA1 described later, for example, are preferable: in an atmospheric furnace, when the rolled wire rod is heated from room temperature to 730°C, the average heating rate is set to 50°C/h or more at least from 500°C to 730°C, then the rolled wire rod is heated to 740°C at an average heating rate of 2 to 5°C/h and held at 740°C for 1 to 3 hours, and then cooled to 720°C at an average cooling rate of 20°C/h or more, cooled to 640°C at an average cooling rate of 8 to 12°C/h, and then left standing still to cool.

[0052] In the above-mentioned spheroidizing annealing conditions, when the rolled wire rod is heated from room temperature to 730°C, the average heating rate is set to 50°C/h or more at least from 500°C to 730°C to suppress grain growth of the metal structure. The average heating rate in this case is more preferably 60°C/h or more. However, if the average heating rate is too high, the rolled wire rod has difficulty in following the temperature, and therefore the average heating rate is preferably 200°C/h or less, more preferably 150°C/h or less.

[0053] Incidentally, the average heating rate in heating from room temperature to 500°C is usually 100°C/h or more. An average heating rate in this temperature range has little influence on grain growth of the metal structure. In view of productivity, the heating rate in this case is preferably high, for example, 120°C/h or more, more preferably 140°C/h or more. The upper limit of the average heating rate in this case is preferably 200°C/h, more preferably 150°C/h, as in the average heating rate in heating from 500°C to 730°C. The average heating rate in heating from room temperature to 500°C may be the same as or different from the average heating rate in heating at least from 500°C to 730°C. In short, in order for the grain boundary cementite to be likely to precipitate by making the original pearlite size small to reduce the intragranular precipitation of cementite, the average heating rate in heating at least from 500°C to 730°C should be 50°C/h or more.

[0054] Further, by controlling the average heating rate in heating from 730°C, which is immediately above point A1, to 740°C to 2 to 5°C/h, it is possible to sufficiently decompose and dissolve cementite in the pearlite structure while suppressing grain growth of the metal structure as much as possible. When the average heating rate is higher than 5°C/h, it is difficult to secure sufficient time for decomposition and dissolution of cementite in the pearlite structure, whereas when the average heating rate is lower than 2°C/h, the heating time from 730°C to 740°C is prolonged and it becomes difficult to suppress grain growth of the metal structure. The average heating rate in this case is more preferably 3°C/h or more and 4°C/h or less.

[0055] At 740°C, the rolled wire rod is preferably held for 1 to 3 hours. When the holding temperature is shorter than 1 hour, decomposition and dissolution of cementite in the pearlite structure are insufficient, whereas when it is longer than 3 hours, it becomes difficult to suppress grain growth of the metal structure. The holding time in this case is more preferably 1.5 hours or more and 2.5 hours or less.

[0056] Grain growth of the metal structure can be suppressed by holding the rolled wire rod as described above and then setting the average cooling rate to 720°C preferably to 20°C/h or more. The average cooling rate in this case is more preferably 30°C/h or more. However, if the average cooling rate is too high, the rolled wire rod has difficulty in following the temperature, and therefore the average cooling rate is preferably set to 100°C/h or less.

[0057] Then, by controlling the average cooling rate in cooling from 720°C to 640°C to 8 to 12°C/h, it is possible to preferentially precipitate cementite in the ferrite grain boundaries and suppress precipitation of cementite having a large aspect ratio, such as cementite in a pearlite structure. When the average cooling rate is lower than 8°C/h, it is difficult to suppress grain growth of the metal structure, whereas when the average cooling rate is higher than 12°C/h, cementite having a large aspect ratio, such as cementite in a pearlite structure, reprecipitates in a large amount. The average cooling rate in this case is more preferably 9°C/h or more and 11°C/h or less.

[0058] Spheroidizing annealing as described above may be repeated a plurality of times. Repetition of such a process reduces the aspect ratio of individual cementite particles and increases the grain boundary cementite percentage. For example, as shown in Test Nos. 7, 12, 14, 19, and 27 in the examples described later, even in the case of steel types C, E, F, H and K for which the production conditions of the rolled wire rod are not appropriately controlled, repeatedly performing the subsequent predetermined spheroidizing annealing makes the grain boundary cementite percentage fall within an appropriate range, and reduces both the deformation resistance and crack occurrence rate.

[0059] The number of repetitions of the spheroidizing annealing is preferably at least 3. However, the grain boundary cementite percentage does not change so much if the spheroidizing annealing is excessively repeated, and thus the number of repetitions is preferably not more than 10. Incidentally, when the spheroidizing annealing is repeated a plurality of times, the spheroidizing annealing may be repeated under the same conditions, or may be repeated under different conditions within the range of the preferable conditions described above.

EXAMPLES

[0060] Hereinafter, the present invention will be described more specifically with reference to examples. The present invention is not restricted by the following examples, and it is of course possible to carry out the present invention with appropriate modifications as long as such modifications conform to the gist described above and below, and all of such modifications are included in the technical scope of the present invention.

[0061] Steel having the chemical component composition shown in Table 1 below was rolled under various production conditions shown in Table 2 below to prepare a wire rod of φ 17.0 mm. In Table 2, cooling 1, cooling 2 and cooling 3 respectively correspond to the first cooling, the second cooling and the third cooling recommended in the present invention. Steel type B is a comparative example in which the chemical component composition deviates from the prescribed value.

[0062] Steel types C, E, F, H, K, O, P and Q are examples in which rolled wire rods were not produced under appropriate production conditions in the present invention. Among them, steel types C, E, F and K were finished at a high finish rolling temperature. Steel type H is an example in which the rolled wire rod was produced by cooling the steel under conditions in which the cooling rate in cooling 3 corresponding to the third cooling was low, that is, the cooling rate in the second cooling was maintained.

[0063] As for steel type O, after the second cooling to 550°C, the steel was heated to 580°C and subjected to a holding step of holding the steel at 580°C for 120 seconds, left standing still to cool to room temperature, and subjected to a wire drawing step with a reduction of area of 40%. As for steel type P, the cooling was performed at a monotonous cooling rate of only cooling 1. As for steel type Q, after cooling 1 was performed, the steel was subjected to a holding step of holding the steel at 550°C for 60 seconds, left standing still to cool to room temperature, and subjected to rough wire drawing with a reduction of area of 15%.

[Table 1]

Steel type	Chemical component composition (mass%) *The balance is Fe and inevitable impurities											
	C	Si	Mn	P	S	Al	N	Cr	Cu	Ni	Mo	B
A	0.33	0.19	0.478	0.011	0.012	0.022	0.0019	-	-	0.06	0.13	-
B	0.33	0.20	2.56	0.013	0.014	0.019	0.0035	0.22	-	-	-	0.0011
C	0.33	0.23	0.452	0.009	0.015	0.031	0.0029	-	-	0.05	0.12	-
D	0.34	0.21	0.446	0.011	0.017	0.028	0.0028	-	-	-	-	-
E	0.36	0.09	0.412	0.010	0.018	0.028	0.0037	0.25	-	-	-	-
F	0.44	0.12	1.25	0.020	0.016	0.021	0.0025	0.17	-	0.05	-	-
G	0.44	0.17	0.748	0.017	0.012	0.040	0.0049	0.14	-	0.04	-	-
H	0.45	0.41	1.16	0.025	0.033	0.051	0.0050	-	-	-	-	-
I	0.45	0.18	0.730	0.017	0.014	0.041	0.0044	-	-	-	-	-
J	0.45	0.20	0.751	0.016	0.014	0.044	0.0045	-	-	-	-	-
K	0.55	0.17	0.651	0.017	0.010	0.035	0.0022	0.14	0.04	-	-	0.0021
L	0.55	0.18	0.644	0.018	0.012	0.032	0.0023	-	-	-	-	-
M	0.55	0.18	0.656	0.021	0.011	0.035	0.0022	0.12	0.03	-	-	0.0022
N	0.56	0.16	0.639	0.013	0.010	0.033	0.0024	-	-	-	-	-
O	0.44	0.10	0.443	0.009	0.017	0.029	0.0034	-	-	-	-	-
P	0.34	0.13	0.843	0.021	0.019	0.022	0.0031	-	-	-	-	-
Q	0.45	0.18	0.722	0.011	0.010	0.035	0.0041	-	-	-	-	-

[Table 2]

Steel type	Production conditions							
	Finish rolling temperature (°C)	Cooling 1		Cooling 2		Cooling 3		Wire drawing
		Cooling rate (°C/s)	Stop temperature (°C)	Cooling rate (°C/s)	Stop temperature (°C)	Cooling rate (°C/s)	Stop temperature (°C)	Reduction of area (%)
A	1005	21	705	3	645	15	300	-
B	950	17	710	4	635	11	300	-
C	1085	12	720	3	610	7	300	-
D	875	8	730	2	605	12	300	-
E	1155	14	705	3	635	7	300	-
F	1060	12	725	2	630	8	300	-
G	965	10	740	5	620	11	300	-
H	1030	9	730	2	-	2	300	-
I	905	13	720	2	630	11	300	-
J	935	14	710	5	620	12	300	-
K	1080	11	740	4	615	8	300	-
L	920	9	735	3	650	13	300	-
M	955	16	715	4	620	12	300	-
N	995	22	715	3	630	12	300	-
O	1055	22	600	13	550	-	-	40
P	1065	4	300	-	-		-	-
Q	980	23	550	-	-	-	-	15

[0064] Next, each rolled wire rod except steel types O, P and Q was subjected to any of the following (a) to (c) in an atmospheric furnace: (a) spheroidizing annealing in which in heating from room temperature to 730°C, the steel was heated from room temperature to 500°C at an average heating rate of 110°C/h, and from 500°C to 730°C at an average heating rate of 80°C/h, then the steel was heated to 740°C at an average heating temperature of 3°C/h, held at 740°C for 3 hours, then cooled to 720°C at an average cooling rate of 30°C/h, cooled to 640°C at an average cooling rate of 10°C/h, and then left standing still to cool (this annealing condition will be abbreviated as "SA1" hereinafter), (b) spheroidizing annealing in which SA1 is repeated five times (this annealing condition will be abbreviated as "SA2" hereinafter) and (c) spheroidizing annealing in which in heating from room temperature to 730°C, the steel was heated from room temperature to 500°C at an average heating rate of 110°C/h, and from 500°C to 730°C at an average heating rate of 80°C/h, then the steel was heated to 740°C at an average heating rate of 3°C/h, held at 740°C for 3 hours, cooled to 640°C at an average cooling rate of 30°C/h, and then left standing still to cool (this annealing condition will be abbreviated as "SA3" hereinafter). The annealing conditions SA1 and SA2 are preferable annealing conditions in the present invention, and the annealing condition SA3 is an example in which the average cooling rate in cooling from 720°C to 640°C is not appropriately controlled.

[0065] Steel type O was subjected to either of the following (d) and (e) in an atmospheric furnace: (d) spheroidizing annealing in which the steel was heated from room temperature to 680°C at an average heating rate of 80°C/h, held at 680°C for 5 hours, then cooled to 640°C at an average cooling rate of 10°C/h, and then left standing still to cool (this annealing condition will be abbreviated as "SA4" hereinafter) and (e) spheroidizing annealing in which the steel was heated from room temperature to 700°C at an average heating rate of 80°C/h, held at 700°C for 5 hours, then cooled to 640°C at an average cooling rate of 10°C/h, and then left standing still to cool (this annealing condition will be abbreviated as "SA5" hereinafter). The annealing conditions SA4 and SA5 are examples that deviate from preferable annealing conditions in the present invention.

[0066] Steel type P was subjected to either of the following (f) and (g) in an atmospheric furnace: (f) spheroidizing annealing in which a step of heating the steel from room temperature to 740°C at an average heating rate of 80°C/h, and then immediately cooling the steel to 660°C at an average cooling rate of 80°C/h was repeated three times (note that the steel was heated from 660°C from the second time), then the steel was heated from 660°C to 740°C at an average heating rate of 80°C/h, held at 740°C for 30 minutes, then cooled to 660°C at an average cooling rate of 80°C/h, held at 660°C for 1 hour, and then left standing still to cool (this annealing condition will be abbreviated as "SA6" hereinafter) and (g) spheroidizing annealing in which a step of heating the steel from room temperature to 740°C at an average heating rate of 80°C/h, holding the steel at 740°C for 10 minutes, and then cooling the steel to 660°C at an average cooling rate of 80°C/h was repeated three times (note that the steel was heated from 660°C from the second time), then the steel was heated from 660°C to 740°C at an average heating rate of 80°C/h, held at 740°C for 30 minutes, then cooled to 660°C at an average cooling rate of 80°C/h, held at 660°C for 1 hour, and then left standing still to cool (this annealing condition will be abbreviated as "SA7" hereinafter). The annealing conditions SA6 and SA7 are examples that deviate from preferable annealing conditions in the present invention.

[0067] Steel type Q was subjected to either of the following (h) and (i) in an atmospheric furnace: (h) spheroidizing annealing in which the steel was heated from room temperature to 720°C at an average heating rate of 150°C/h, held at 720°C for 1 hour, and then left standing still to cool (this annealing condition will be abbreviated as "SA8" hereinafter) and (i) spheroidizing annealing in which the steel was heated from room temperature to 730°C at an average heating rate of 150°C/h, held at 730°C for 1 hour, and then left standing still to cool (this annealing condition will be abbreviated as "SA9" hereinafter). The annealing conditions SA8 and SA9 are examples that deviate from preferable annealing conditions in the present invention.

[0068] As for the steel wires after the spheroidizing annealing, (1) the bcc-Fe crystal grain size of the metal structure, (2) the grain boundary cementite percentage, (3) the deformation resistance during cold working and (4) the crack occurrence rate during cold working were measured by the following methods.

[0069] In measuring the ferrite grain size and the grain boundary cementite percentage of the steel wire after the spheroidizing annealing, the steel wire was subjected to resin filling so that the cross section could be observed, and the cut surface was mirror polished with emery paper and diamond buff. The measurement was performed at a position of D/4 from the surface of the steel wire, wherein D is the radius D of the steel wire.

(1) Measurement of bcc-Fe crystal grain size

[0070] The bcc-Fe crystal grain size was measured using an EBSP analyzer and a FE-SEM (Field-Emission Scanning Electron Microscope). For the analysis tool, OIM software available from TSL Solutions K.K. was used. A "crystal grain" was defined with respect to the boundary having a crystal orientation difference (also referred to as "bevel angle") larger than 15°, that is, a high-angle grain boundary as the crystal grain boundary, and an average value of diameters in converting the area of the bcc-Fe crystal grains into a circle, that is, the average equivalent circle diameter was calculated. The measurement field was set to 200 μm × 400 μm, the measurement step interval was set to 1.0 μm, and any measurement point with a confidence index, that shows the reliability of the measurement orientation, of 0.1 or less was eliminated from the analysis target.

(2) Measurement of grain boundary cementite percentage

[0071] In the measurement of the grain boundary cementite percentage, ferrite grain boundaries and cementite were made to appear by picral etching over 5 minutes or more, the structure was observed with an optical microscope, and three fields of view were photographed at a magnification of 1000 times. Ten horizontal lines were drawn on the photographs at equal intervals and the number of grain boundary cementite particles and the number of intragranular cementite particles present on the lines were counted. The grain boundary cementite percentage was calculated by dividing the number of grain boundary cementite particles present in three fields of view by the total number of cementite particles present in the same fields of view. The minimum equivalent circle diameter of the cementite particles measured was set to 0.3 μm. Herein, cementite particles that were in contact with the ferrite grain boundary and had an aspect ratio of 3.0 or less were defined as grain boundary cementite. Therefore, even if the cementite particles were in contact with the ferrite grain boundary, particles having an aspect ratio exceeding 3.0 were defined as intragranular cementite.

(3) Measurement of Deformation Resistance

[0072] A sample for cold forging test of φ 10.0 mm × 15.0 mm was prepared from a steel wire and subjected to a cold forging test at a processing rate of 60% five times using a forging press at a strain rate of 5/sec to 10/sec at room temperature. For the measurement of the deformation resistance, the deformation resistance at 40% processing was measured five times from the data of processing rate-deformation resistance obtained from the cold forging test at the processing rate of 60%, and the average value of the five measurements was obtained. The acceptance criterion of the deformation resistance in steel types A to E and P having a C content in the range of 0.3 to less than 0.4% is 650 MPa or less. The acceptance criterion of the deformation resistance in steel types F to J, O and Q having a C content in the range of 0.4 to less than 0.5% is 680 MPa or less. The acceptance criterion of the deformation resistance in steel types K to N having a C content in the range of 0.5 to 0.6% is 730 MPa or less.

(4) Measurement of crack occurrence rate

[0073] A sample for cold forging test of φ 10.0 mm × 15.0 mm was prepared from a steel wire and subjected to a cold forging test at a processing rate of 60% five times using a forging press at a strain rate of 5/sec to 10/sec at room temperature. For the measurement of the crack occurrence rate, after the cold forging test at a processing rate of 60%, the surface observation was carried out five times each with a stereomicroscope, the presence or absence of surface cracks was confirmed at a magnification of 20 times, and the average was obtained by dividing "the number of samples having surface cracks" by 5. The acceptance criterion of the crack occurrence rate is 20% or less in all steel types.

[0074] These results are shown in Table 3 together with spheroidizing annealing conditions. In the column of "comprehensive evaluation" in Table 3, "O.K." is given to an example in which both of reduction in deformation resistance and improvement in crack resistance are achieved, and "N.G." is given to an example in which at least either of reduction in deformation resistance and improvement in crack resistance is not achieved.

[Table 3]

Test No.	Steel type	Annealing condition	Bcc-Fe crystal grain size (μm)	Grain boundary cementite percentage (%)	Deformation resistance (MPa)	Crack occurrence rate (%)	Comprehensive evaluation
1	A	SA1	17.3	42	645	20	O.K.
2		SA2	18.2	65	623	0	O.K.
3		SA3	17.5	26	682	60	N.G.
4	B	SA1	14.0	55	680	20	N.G.
5		SA2	14.8	68	665	0	N.G.
6	C	SA1	27.2	28	678	80	N.G.
7		SA2	28.1	50	641	20	O.K.

(continued)

Test No.	Steel type	Annealing condition	Bcc-Fe crystal grain size (μm)	Grain boundary cementite percentage (%)	Deformation resistance (MPa)	Crack occurrence rate (%)	Comprehensive evaluation
8	D	SA1	5.8	60	637	0	O.K.
9		SA2	5.7	72	616	0	O.K.
10		SA3	6.1	38	652	20	N.G.
11	E	SA1	33.6	21	682	100	N.G.
12		SA2	35.1	43	646	20	O.K.
13	F	SA1	23.6	36	683	60	N.G.
14		SA2	22.4	55	652	20	O.K.
15	G	SA1	15.3	42	661	20	O.K.
16		SA2	15.5	60	655	0	O.K.
17		SA3	15.5	29	704	40	N.G.
18	H	SA1	20.1	33	691	40	N.G.
19		SA2	22.3	61	668	20	O.K.
20	I	SA1	8.8	58	639	0	O.K.
21		SA2	9.1	71	634	0	O.K.
22		SA3	8.5	33	682	20	N.G.
23	J	SA1	11.6	55	663	20	O.K.
24		SA2	11.8	66	643	0	O.K.
25		SA3	10.6	22	723	40	N.G.
26	K	SA1	24.6	36	753	40	N.G.
27		SA2	24.4	54	698	20	O.K.
28	L	SA1	10.2	48	722	20	O.K.
29		SA2	11.0	63	701	0	O.K.
30		SA3	10.5	30	744	60	N.G.
31	M	SA1	13.2	47	725	20	O.K.
32		SA2	13.5	65	688	0	O.K.
33		SA3	12.9	24	762	40	N.G.
34	N	SA1	16.2	42	726	20	O.K.
35		SA2	17.8	55	695	20	O.K.
36		SA3	16.6	22	759	80	N.G.
37	O	SA4	20.6	31	691	60	N.G.
38		SA5	21.2	37	684	40	N.G.
39	P	SA6	22.2	34	672	40	N.G.
40		SA7	23.0	33	667	40	N.G.
41	Q	SA8	17.5	28	699	40	N.G.
42		SA9	17.3	34	686	40	N.G.

[0075] The following consideration can be made from the results in Table 3. It is understood that Test Nos. 1, 2, 7 to

9, 12, 14 to 16, 19 to 21, 23, 24, 27 to 29, 31, 32, 34 and 35 are examples that satisfy all the requirements defined in the present invention, and both of reduction in deformation resistance and improvement in crack resistance are achieved in these examples.

[0076] Among them, Test Nos. 7, 12, 14, 19 and 27 are examples in which steel type C, E, F, H or K which is not produced under preferable rolled wire rod conditions was used. Nevertheless, after the annealing of SA2 in which SA1 annealing is repeated, the grain boundary cementite sufficiently precipitated, and both the deformation resistance and crack occurrence rate reached the acceptance criteria. Among them, in Test No. 12, although the bcc-Fe crystal grain size was slightly larger than the preferable range, both the deformation resistance and crack occurrence rate reached the acceptance criteria.

[0077] Focusing attention on Test Nos. 1 and 2 (steel type A), Test Nos. 6 and 7 (steel type C), Test Nos. 8 and 9 (steel type D), Test Nos. 11 and 12 (steel type E), Test Nos. 13 and 14 (steel type F), Test Nos. 15 and 16 (steel type G), Test Nos. 18 and 19 (steel type H), Test Nos. 20 and 21 (steel type I), Test Nos. 23 and 24 (steel type J), Test Nos. 26 and 27 (steel type K), Test Nos. 28 and 29 (steel type L), Test Nos. 31 and 32 (steel type M) and Test Nos. 34 and 35 (steel type N) that were subjected to both the annealing conditions SA1 and SA2, it is understood that the sample subjected to SA2 annealing in which SA1 is repeated five times was reduced in both the deformation resistance and crack occurrence rate as compared with the sample subjected to SA1 annealing in all the cases.

[0078] In contrast, Test Nos. 3 to 6, 10, 11, 13, 17, 18, 22, 25, 26, 30, 33 and 36 to 42 are comparative examples not satisfying any of the requirements defined in the present invention. It is understood that either or both the deformation resistance and crack occurrence rate did not reach the acceptance criteria in these comparative examples.

[0079] More specifically, Test Nos. 3, 10, 17, 22, 25, 30, 33 and 36 are examples in which the spheroidizing annealing was performed under SA3 which is an inappropriate condition, the grain boundary cementite percentage was insufficient, and either or both the deformation resistance and crack occurrence rate did not reach the acceptance criteria.

[0080] Test Nos. 4 and 5 are examples in which steel type B having an excess Mn content was used, and the deformation resistance during cold working remained high.

[0081] Test Nos. 6, 11, 13, 18 and 26 are examples in which steel type C, E, F, H or K which was not produced under preferable conditions for producing the rolled wire rod was used. No grain boundary cementite precipitated by the subsequent spheroidizing annealing under SA1, and neither the deformation resistance nor the crack occurrence rate reached the acceptance criterion. However, when these steel types were subjected to SA2 spheroidizing annealing in which SA1 is repeated five times, grain boundary cementite appropriately precipitated, and both the deformation resistance and crack occurrence rate reached the acceptance criteria (Test Nos. 7, 12, 14, 19 and 27).

[0082] Test Nos. 37 and 38 are examples in which the spheroidizing annealing was carried out under SA4 or SA5 which is an inappropriate condition using steel type O which was not produced under preferable conditions for producing the rolled wire rod. In these tests, fine cementite particles uniformly dispersed, the grain boundary cementite percentage was small, the deformation resistance remained high, and the crack occurrence rate exceeded the acceptance criterion.

[0083] Test Nos. 39 and 40 are examples in which the spheroidizing annealing was carried out under SA6 or SA7 which is an inappropriate condition using steel type P which was not produced under preferable conditions for producing the rolled wire rod. In these tests, spheroidized cementite particles dispersed in the ferrite grains during spheroidizing annealing with fragmented lamellar cementite as nuclei, the grain boundary cementite percentage was small, the deformation resistance remained high, and the crack occurrence rate exceeded the acceptance criterion.

[0084] Test Nos. 41 and 42 are examples in which the spheroidizing annealing was carried out under SA8 or SA9 which is an inappropriate condition using steel type Q which was not produced under preferable conditions for producing the rolled wire rod. In these tests, lamellar cementite fragmented during rolling was produced in a large amount, the grain boundary cementite percentage after the spheroidizing annealing was small, the deformation resistance remained high, and the crack occurrence rate exceeded the acceptance criterion.

INDUSTRIAL APPLICABILITY

[0085] The steel wire for mechanical structural parts of the present invention is suitably used as a material for various mechanical structural parts such as automobile parts and construction machinery parts produced by cold working such as cold forging, cold heading and cold rolling. Specific examples of such mechanical structural parts include mechanical parts and electrical parts, more specifically, bolts, screws, nuts, sockets, ball joints, inner tubes, torsion bars, clutch cases, cages, housings, hubs, covers, cases, washers, tappets, saddles, valves, inner cases, clutches, sleeves, outer races, sprockets, cores, stators, anvils, spiders, rocker arms, bodies, flanges, drums, joints, connectors, pulleys, clasps, yokes, mouthpieces, valve lifters, spark plugs, pinion gears, steering shafts and common rails. The steel wire of the present invention is industrially useful as a steel wire for high-strength mechanical structural parts that are suitably used as a material for the above-mentioned mechanical structural parts. The steel wire can exhibit excellent cold workability since it has low deformation resistance at room temperature and is suppressed in cracks of the material in the production of the mechanical structural parts.

[0086] This application claims the priority of Japanese Patent Application No. 2015-073776 filed on March 31, 2015 as a basic application. Japanese Patent Application No. 2015-073776 is hereby incorporated by reference.

Claims

1. A steel wire for mechanical structural parts, comprising, in mass%,
   0.3 to 0.6% of C,
   0.05 to 0.5% of Si,
   0.2 to 1.7% of Mn,
   more than 0% and 0.03% or less of P,
   0.001 to 0.05% of S,
   0.005 to 0.1% of Al, and
   0 to 0.015% of N, the balance being iron and inevitable impurities,
   wherein steel of the steel wire has a metal structure formed of ferrite and cementite, and the number proportion of cementite particles present in ferrite grain boundaries is 40%, or more based on the total number of cementite particles.

2. The steel wire for mechanical structural parts according to claim 1, further comprising, in mass%, at least one component selected from the group consisting of:

   more than 0% and 0.5% or less of Cr,
   more than 0% and 0.25% or less of Cu,
   more than 0% and 0.25% or less of Ni,
   more than 0% and 0.25% or less of Mo, and
   more than 0% and 0.01% or less of B.

3. The steel wire for mechanical structural parts according to claim 1 or 2, wherein the average equivalent circle diameter of bcc-Fe crystal grains in the metal structure is 30 μm or less.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2016/058379

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C22C38/60*(2006.01)i, *C21D8/06*(2006.01)n

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

B. FIELDS SEARCHED

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

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

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2013-147728 A (Kobe Steel, Ltd.), 01 August 2013 (01.08.2013), claims; paragraphs [0001], [0043] to [0084] & US 2014/0326369 A1 claims; paragraphs [0001], [0044] to [0080] & EP 2796586 A1 & WO 2013/094475 A1	1-3
A	JP 2013-7091 A (Kobe Steel, Ltd.), 10 January 2013 (10.01.2013), claims (Family: none)	1-3
A	JP 2-185917 A (Sumitomo Metal Industries, Ltd.), 20 July 1990 (20.07.1990), claims; examples; fig. 5 to 7 (Family: none)	1-3

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

*	Special categories of cited documents:
"A"	document defining the general state of the art which is not considered to be of particular relevance
"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

Date of the actual completion of the international search
06 May 2016 (06.05.16)

Date of mailing of the international search report
17 May 2016 (17.05.16)

Name and mailing address of the ISA/
Japan Patent Office
3-4-3,Kasumigaseki,Chiyoda-ku,
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Authorized officer

Telephone No.

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

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2016/058379

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 1-104718 A (Nippon Steel Corp.), 21 April 1989 (21.04.1989), claims; examples; fig. 1 (Family: none)	1-3
P,A	JP 2016-20537 A (Kobe Steel, Ltd.), 04 February 2016 (04.02.2016), claims & WO 2015/194411 A1	1-3

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- WO 2011108459 A **[0008]**
- JP 2012140674 A **[0008]**
- JP 2006316291 A **[0008]**
- JP 2015073776 A **[0086]**