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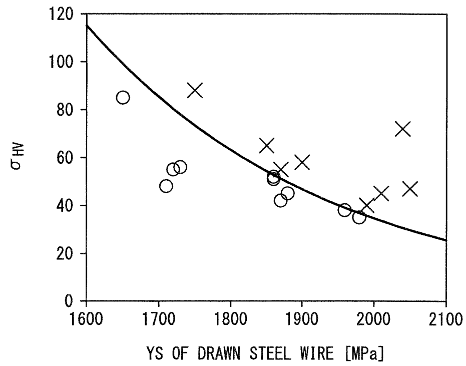
(54) STEEL WIRE

(57) A drawn steel wire has a predetermined chemical composition; in a region of the drawn steel wire that is closer to an axis line than a depth of 100 μm from a surface of the drawn steel wire in a lengthwise-section that includes the axis line of the drawn steel wire, a metallographic structure includes 90% or more of a drawn pearlite by an area ratio; in a region of the drawn steel wire that is the depth of 100 μm from the surface of the drawn steel wire in the lengthwise-section, the metallographic structure includes 70% or more of the drawn pearlite by the area ratio; when D in units of millimeters represents a diameter of the drawn steel wire, σ_{HV} represents a standard deviation of a Vickers hardness of the surface of the drawn steel wire, and $Rp_{0.2}$ represents a yield strength of the drawn steel wire, $\sigma_{HV} < (-9500 \times \ln(D) + 30000) \times \exp(-0.003 \times Rp_{0.2})$ is satisfied, and a tensile strength TS of the drawn steel wire is 1770 MPa or higher.

FIG. 2



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Description

[Technical Field of the Invention]

[0001] The present invention relates to a high strength drawn steel wire having a tensile strength TS of 1770 MPa or more.

[0002] Priority is claimed on Japanese Patent Application No. 2016-139744, filed on July 14, 2016, the content of which is incorporated herein by reference.

[Related Art]

[0003] A bare drawn steel wire obtained by wire drawing a high carbon steel wire rod, or a coated drawn steel wire obtained by wire drawing a wire rod and thereafter coating the wire rod with Zn plating or the like is used for various applications such as a drawn steel wire for a bridge cable, a drawn steel wire for prestressed concrete, and a drawn steel wire used for various drawn steel wire ropes. Such drawn steel wires are required to have, as important properties, excellent torsional property (number of turns depending on the wire diameter) specified, for example, in the JIS G 3521 (hard drawn steel wire) standard as well as tensile strength.

[0004] However, in general, in a torsion test of a drawn steel wire, longitudinal cracks called delamination easily occur as the strength of the drawn steel wire is increased. That is, it becomes difficult to satisfy excellent torsional property as the strength of the drawn steel wire increases.

[0005] Regarding the above-described problem, in Patent Document 1, a drawn steel wire in which the delamination during twisting is suppressed is proposed as a drawn steel wire having excellent torsional property. Patent Document 1 discloses that the delamination is suppressed by adjusting the surface layer hardness in a transverse section of a drawn steel wire depending on the wire diameter.

[0006] However, it is considered that delamination occurs from the weakest point in the longitudinal direction of the drawn steel wire. Therefore, it is difficult to reliably suppress the delamination merely by controlling the surface layer hardness of a specific transverse section.

[0007] Patent Document 2 discloses a hot dip galvanized drawn steel wire which satisfies torsional property while suppressing proeutectoid cementite by controlling the TS of the drawn steel wire depending on the Si content, the Al content, and the wire diameter. However, in Patent Document 2, only the tensile strength of the drawn steel wire is controlled by the balance between the Si content and Al content, and variations in the structure or mechanical properties of the drawn steel wire for suppressing delamination are not adjusted. Therefore, in Patent Document 2, high strength and the suppression of the delamination are not substantially compatible with each other.

[0008] In the related art, it is considered that torsional property is improved by suppressing the delamination. However, the inventors have found that there are cases where the number of turns (number of turns) until fracture is decreased even when delamination does not occur. Therefore, in consideration of the safety of a structure, not only the delamination is not occurred, but also a number of turns is sufficient, as the torsional property, is required of a drawn steel wire.

[0009] Patent Document 3 discloses that the mass ratio between Ti and N is specified, and the half-width of the (110) plane of ferrite and residual stress on the surface of a drawn steel wire are controlled to cause the yield ratio YR (the ratio between the yield strength YS and the tensile strength TS) to be 80% or less, thereby obtaining a drawn steel wire with no delamination occurred.

[0010] However, in Patent Document 3, a number of turns is not examined although the delamination is examined.

[Prior Art Document]

[Patent Document]

[0011]

[Patent Document 1] Japanese Patent No. 3984393
[Patent Document 2] Japanese Patent No. 3036393
[Patent Document 3] Japanese Patent No. 4377715

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0012] The present invention has been made against a background of the above-described circumstances. An object of the present invention is to provide a drawn steel wire having excellent torsional property, in which delamination does not occur in a torsion test and a sufficient number of turns is shown.

[Means for Solving the Problem]

[0013] The inventors focused on flow stress due to torsional deformation in the longitudinal direction and the circumferential direction of a drawn steel wire regarding the behavior during occurring delamination, and examined the suppression of the delamination and the improvement in a number of turns. As a result, it was found that the unevenness of strain on the outermost surface due to torsional deformation is decreased by reducing the unevenness of flow stress of the outermost layer regarding the yield stress and the wire diameter of the entire drawn steel wire, resulting in the improvement in torsional property, and the present invention has been completed.

[0014] The present invention has been made on the basis of the above-described knowledge, and the gist thereof is as follows.

(1) A drawn steel wire according to an aspect of the present invention includes, as a chemical composition, by mass%, C: 0.75% to 1.10%, Si: 0.10% to 1.40%, Mn: 0.10% to 1.0%, Al: 0% to 0.10%, Ti: 0% to 0.10%, Cr: 0% to 0.60%, V: 0% to 0.10%, Nb: 0% to 0.10%, Mo: 0% to 0.20%, W: 0% to 0.50%, B: 0% to 0.0030%, N: limited to 0.0060% or less, P: limited to 0.030% or less, S: limited to 0.030% or less, and a remainder including Fe and impurities; in a region of the drawn steel wire that is closer to an axis line than a depth of 100 μm from a surface of the drawn steel wire in a lengthwise-section that includes the axis line of the drawn steel wire, a metallographic structure includes 90% or more of a drawn pearlite by an area ratio; in a region of the drawn steel wire that is the depth of 100 μm from the surface of the drawn steel wire in the lengthwise-section, the metallographic structure includes 70% or more of the drawn pearlite by the area ratio; when D in units of millimeters represents a diameter of the drawn steel wire, σ_{HV} represents a standard deviation of a Vickers hardness of the surface of the drawn steel wire, and $Rp_{0.2}$ represents a yield strength of the drawn steel wire, Expression (a) is satisfied; and a tensile strength of the drawn steel wire is 1770 MPa or higher.

$$\sigma_{HV} < (-9500 \times \ln(D) + 30000) \times \exp(-0.003 \times Rp_{0.2}) \ldots (a)$$

(2) In the drawn steel wire according to (1), the chemical composition may include, by mass%, at least one selected from the group consisting of Al: 0.001% to 0.10%, Ti: 0.001% to 0.10%, Cr: more than 0% and 0.60% or less, V: more than 0% and 0.10% or less, Nb: more than 0% and 0.10% or less, Mo: more than 0% and 0.20% or less, W: more than 0% and 0.50% or less, and B: more than 0% and 0.0030% or less.

[0015] In the drawn steel wire according to (1) or (2), a coating layer including one or more of Zn, Al, Cu, Sn, Mg, and Si on the surface of the drawn steel wire may be provided.

[0016] In the present invention, as a yield strength YS, 0.2% proof stress ($Rp_{0.2}$) is employed.

[Effects of the Invention]

[0017] According to the aspect of the present invention, it is possible to obtain drawn steel wire having good torsional property by appropriately controlling the chemical composition and the metallographic structure of the drawn steel wire, and suppressing the hardness distribution of the surface of the drawn steel wire to be in an appropriate range depending on the yield strength and the wire diameter of the drawn steel wire. Such a drawn steel wire is used as a drawn steel wire used for applications for various ropes such as a bridge cable, a drawn steel wire for prestressed concrete, and ACSR, and besides, it is useful as a drawn steel wire used for applications in which torsion (twisting) is primarily applied.

[Brief Description of the Drawings]

[0018]

FIG. 1 is a photograph of the surface of a drawn steel wire after hardness measurement is performed on the surface of the drawn steel wire.

FIG. 2 is a graph showing the relationship between a σ_{HV} threshold and a yield strength ($Rp_{0.2}$), and torsional property of a drawn steel wire having a wire diameter of 5.0 mm to 5.4 mm in examples regarding each of present invention examples and comparative examples.

FIG. 3 is a schematic view showing a method of determining a number of turns in a torsion test.

[Embodiments of the Invention]

[0019] Hereinafter, a drawn steel wire according to an embodiment of the present invention (a drawn steel wire according to this embodiment) will be described in detail.

<Chemical Composition>

[0020] First, the reason for limiting the chemical composition (composition) in the drawn steel wire according to this embodiment will be described. Hereinafter, all % used for each chemical composition means mass%.

[C: 0.75% to 1.10%]

[0021] C is an element which contributes to high-strengthening of the drawn steel wire by increasing the cementite fraction and refining the lamellar spacing of pearlite. When the C content is less than 0.75%, it is difficult to form pearlite as the principal structure. Therefore, the C content is set to 0.75% or more. The C content is preferably 0.77% or more, and more preferably 0.80% or more. On the other hand, when the C content exceeds 1.10%, proeutectoid cementite precipitates in a wire rod which is the material of the drawn steel wire, and the ductility of the wire rod is deteriorated. In this case, it becomes difficult to perform wire drawing when the drawn steel wire is produced from the wire rod, and the ductility of the drawn steel wire is also deteriorated. Therefore, the C content is set to 1.10% or less. The C content is preferably 1.05% or less, and more preferably 1.00% or less.

[Si: 0.10% to 1.40%]

[0022] Si is a deoxidizing element and is an element for solid solution strengthening of ferrite. When the Si content is less than 0.10%, sufficient hardenability cannot be secured during heat treatment. In a case where the drawn steel wire is subjected to zinc plating, it is difficult to control an alloy layer. Therefore, the Si content is set to 0.10% or more. The Si content is preferably 0.12% or more, and more preferably 0.15% or more. On the other hand, when the Si content is excessive, decarburization during heating is promoted, and the performance for the mechanical descaling is deteriorated. In addition, a non-pearlite structure is increased during patenting. Therefore, the Si content is set to 1.40% or less. The Si content is preferably 1.30% or less, and more preferably 1.25% or less.

[Mn: 0.10% to 1.0%]

[0023] Mn is a deoxidizing element and is an element which improves the hardenability of steel. When the Mn content is less than 0.10%, sufficient hardenability cannot be secured during the heat treatment. Therefore, the Mn content is set to 0.10% or more. The Mn content is preferably 0.20% or more, more preferably 0.30% or more. On the other hand, when the Mn content exceeds 1.0%, a pearlitic transformation is delayed and it is difficult to obtain a desired microstructure. Therefore, the Mn content is set to 1.0% or less. The Mn content is preferably 0.90% or less, and more preferably 0.80% or less.

[0024] The drawn steel wire according to this embodiment has the essential elements described above, and the remainder thereof basically includes Fe and impurities. However, in addition to each elements described above, one or more selected from the group consisting of Al, Ti, Cr, V, Nb, Mo, W, and B may be included in the drawn steel wire within the ranges described below. That is, the drawn steel wire includes the essential elements and may include one or more selected from the group consisting of Al, Ti, Cr, V, Nb, Mo, W, and B, and the remainder thereof is Fe and impurities. Al, Ti, Cr, V, Nb, Mo, W, and B are optional elements, and do not need to be necessarily included in the drawn steel wire. Therefore, the lower limit thereof is 0%.

[0025] In addition, the impurities are elements incorporated from the raw materials such as ore or scrap when steel is industrially manufactured, or from various environments in a manufacturing process, and are allowed in a range in which the properties of the steel are not adversely affected.

[Al: 0% to 0.10%]

[0026] Al is an element effective as a deoxidizing element. In a case of obtaining this effect, it is preferable to set the Al content to 0.001% or more. The Al content is more preferably 0.005% or more, and even more preferably 0.010% or more. On the other hand, when the Al content is excessive, coarse hard inclusions are formed. In this case, drawability is deteriorated, and stability in continuous casting is deteriorated. Therefore, even in a case of including Al, the Al content is set to 0.10% or less. The Al content is preferably 0.080% or less, and more preferably 0.070% or less.

[Ti: 0% to 0.10%]

[0027] Ti is an element which is effective as a deoxidizing element and has an action of fixing N in steel and improving drawability. Furthermore, Ti is an element which precipitates as Ti(C, N), functions as pinning particles, and contributes to the refinement of austenite grains. In a case of obtaining these effects, it is preferable to set the Ti content to 0.001% or more. The Ti content is more preferably 0.005% or more, and even more preferably 0.010% or more. On the other hand, when the Ti content is excessive, coarse TiN is formed in a casting stage, and drawability is deteriorated. Therefore, even in a case of including Ti, the Ti content is set to 0.10% or less. The Ti content is preferably 0.03% or less, and more preferably 0.025% or less.

[Cr: 0% to 0.60%]

[0028] Cr is an element which improves hardenability. In addition, Cr is an element which improves the strength of the drawn steel wire by refining the lamellar spacing of pearlite. In a case of obtaining these effects, it is preferable to set the Cr content to be more than 0%. The Cr content is more preferably 0.05% or more. On the other hand, Cr is an element which stabilizes cementite. Therefore, when the Cr content is excessive, not only the time until the end of a pearlitic transformation is increased, but also proeutectoid cementite is easily formed. In addition, the performance for the mechanical descaling is deteriorated. Therefore, even in a case of including Cr, the Cr content is set to 0.60% or less. The Cr content is preferably 0.50% or less, and more preferably 0.40% or less.

[V: 0% to 0.10%]

[0029] V is an element which improves hardenability, and is an element which contributes to the refinement of austenite grains when precipitated as carbonitrides in an austenite region and contributes to strengthening of the drawn steel wire when precipitated in a ferrite region. In a case of obtaining these effects, it is preferable to set the V content to more than 0%. The V content is more preferably 0.05% or more.

[0030] On the other hand, when the V content is excessive, the time until the end of the pearlitic transformation is increased, and not only it becomes difficult to form a required metallographic structure, but also the torsional property of the drawn steel wire is deteriorated due to precipitation strengthening of carbonitride. Therefore, even in a case of including V, the V content is set to 0.10% or less. The V content is preferably 0.085% or less, and more preferably 0.070% or less.

[Nb: 0% to 0.10%]

[0031] Nb is an element which improves hardenability and is an element which contributes to the refinement of austenite grain sizes by its carbonitride acting as pinning particles. In a case of obtaining these effects, it is preferable to set the Nb content to more than 0%. The Nb content is more preferably 0.003% or more.

[0032] On the other hand, when the Nb content is excessive, the time until the end of pearlitic transformation is increased, so that it becomes difficult to form a required metallographic structure. Therefore, even in a case of including Nb, the Nb content is set to 0.10% or less. The Nb content is preferably 0.04% or less, and more preferably 0.03% or less.

[Mo: 0% to 0.20%]

[0033] Mo is an element which improves the hardenability of steel and is an element which contributes to the refinement of austenite grain sizes by a solute drug. In a case of obtaining these effects, it is preferable to set the Mo content to more than 0%. The Mo content is more preferably 0.03% or more.

[0034] On the other hand, when the Mo content is excessive, the time until the end of the pearlitic transformation is increased, so that it becomes difficult to form a required metallographic structure. Therefore, even in a case of including Mo, the Mo content is set to 0.20% or less. The Mo content is preferably 0.10% or less, and more preferably 0.07% or less.

[W: 0% to 0.50%]

[0035] W is an element which improves the hardenability of steel. In a case of obtaining this effect, it is preferable to set the W content to more than 0%. The W content is more preferably 0.06% or more.

[0036] On the other hand, when the W content is excessive, the time until the end of the pearlitic transformation is increased, so that it becomes difficult to form a required metallographic structure. Therefore, even in a case of including W, the W content is set to 0.50% or less. The W content is preferably 0.20% or less, and more preferably 0.10% or less.

[B: 0% to 0.0030%]

[0037] B is an element which segregates at the grain boundary in a solid solution state and suppresses the formation of ferrite, thereby improving drawability. In addition, B is an element having an action for decreasing the amount of solute N by precipitating as BN. In a case of obtaining these effects, it is preferable to set the B content to more than 0%. The B content is more preferably 0.0003% or more.

[0038] On the other hand, when the B content is excessive, carbides of $M_{23}(C, B)_6$ precipitate at the grain boundary, and the drawability is deteriorated. Therefore, even in a case of including B, the B content is set to 0.0030% or less. The B content is preferably 0.0025% or less.

[0039] In the drawn steel wire according to this embodiment, N, P, and S among the impurities are particularly harmful, so that the amounts thereof need to be limited.

[N: 0.0060% or Less]

[0040] N is an element which deteriorates the torsional property of the drawn steel wire when present in a solid solution state in steel and thus deteriorates the drawability due to strain aging during wire drawing. Therefore, N is an element to be reduced as much as possible. When the N content exceeds 0.0060%, variation in the hardness of the surface of the drawn steel wire is increased, and the range specified in this embodiment cannot be satisfied. Therefore, the N content is limited to 0.0060% or less. The N content is preferably 0.0040% or less. The N content is preferably small. However, when the N content is controlled to less than 0.0010%, the costs in actual production is significantly increased and it influences for controlling other impurities. Therefore, in consideration of the actual production, the N content may be set to 0.0010% or more.

[P: 0.030% or Less]

[0041] P is an element which contributes to solid solution strengthening of ferrite. At the same time, however, P is also an element which significantly reduces the ductility of steel. In particular, when the P content exceeds 0.030%, the drawability is significantly decreased during wire drawing from a wire rod to the drawn steel wire with a deterioration in ductility. Therefore, the P content is limited to 0.030% or less. The P content is preferably limited to 0.020% or less, and is more preferably limited to 0.012% or less.

[0042] The P content is preferably small. However, when the P content is limited to less than 0.003%, the cost is significantly increased. Therefore, in consideration of the actual production, the P content may be set to 0.003% or more.

[S: 0.030% or Less]

[0043] S is an element which causes red shortness and is also an element which decreases the ductility of steel. When the S content exceeds 0.030%, the decrease in ductility becomes significant. Therefore, the S content is limited to 0.030% or less. The S content is preferably limited to 0.020% or less, and is more preferably limited to 0.010% or less.

[0044] The S content is preferably small. However, when the S content is limited to less than 0.003%, the cost is significantly increased. Therefore, in consideration of the actual production, the S content may be set to 0.003% or more.

<Metallographic Structure of Drawn steel wire>

[0045] In the drawn steel wire according to this embodiment, it is effective to adjust the chemical composition as described above and simultaneously make the metallographic structure an appropriate structure in order to improve the torsional property.

[0046] The metallographic structure of the drawn steel wire according to this embodiment primarily includes drawn pearlite which is stretched by wire drawing pearlite having a lamellar structure of ferrite and cementite. Specifically, the drawn pearlite indicates pearlite in which the ratio between the maximum length in the axial direction of pearlite grains and the maximum thickness in the direction perpendicular thereto (maximum length in the axial direction / maximum thickness in the direction perpendicular to the axis), that is, the aspect ratio is 1.05 or more, in a section (lengthwise-section) in an axial direction including the axis line of the drawn steel wire, that is, in an lengthwise-section along the wire drawing direction. There may be cases where, ferrite, proeutectoid cementite, bainite, or martensite is present as a non-pearlite structure in addition to the drawn pearlite in the metallographic structure. However, as the fraction (area ratio) of these structures is increased, the torsional property is deteriorated. Therefore, the area ratio of the drawn pearlite in a region (internal region) of the drawn steel wire that is closer to an axis line than a depth of 100 μm from the surface of the drawn steel wire in the lengthwise-section is set to 90% or more. The area ratio thereof is more preferably set to 95% or more. The area ratio of the drawn pearlite may be 100%.

[0047] On the other hand, in the surface layer portion of the drawn steel wire, decarburization occurs or the cooling rate becomes faster than that inside the wire rod in a patenting process for the wire rod, so that the fraction of ferrite, proeutectoid cementite, bainite, or martensite as the non-pearlite structure other than the drawn pearlite tends to be higher than that inside the drawn steel wire.

[0048] However, as the area ratio of these structures is increased, variation in the hardness of the drawn steel wire is increased, and the torsional property is deteriorated. Therefore, as described above, 90% or more of the drawn pearlite is secured in the internal region of the lengthwise-section of the drawn steel wire and then the area ratio of the drawn pearlite in the metallographic structure in the surface layer region of the drawn steel wire is set to 70% or more, and preferably 85% or more. In this embodiment, the surface layer region of the drawn steel wire means a region from the surface of the drawn steel wire to a depth of 100 μm. That is, in the lengthwise-section of the drawn steel wire, the region from the surface of the drawn steel wire to a depth of 100 μm is the surface layer region, and a region that is closer to the axis line (center side) than the surface layer region is the internal region.

[0049] The area ratio of the drawn pearlite of the surface layer region is an average area ratio of the drawn pearlite in the region of the lengthwise-section from the surface to a depth of 100 μm.

[0050] Specifically, the area ratio of the drawn pearlite in the internal region or the surface layer region of the lengthwise-section is obtained as follows.

[0051] At the surface layer region of the lengthwise-section (a position at a depth of 50 μm from the surface), 1/4 × D (a position at a 1/4 depth of the diameter D of the drawn steel wire from the surface), and 1/2 × D (a position at a 1/2 depth of the diameter D of the drawn steel wire from the surface), five visual fields are observed at a magnification of 2,000-fold using an optical microscope, and the photographs of the structures in the observed visual fields are taken. Image analysis is performed by marking the non-pearlite structure of the taken photograph and the area ratio of pearlite is measured. Here, a region composed of only ferrite and a structure in which cementite is coarsely scattered in ferrite are determined as the non-pearlite structure. In addition, pearlite in which the ratio between the maximum length in the axial direction of pearlite grains and the maximum thickness in the direction perpendicular thereto (maximum length in the axial direction / maximum thickness in the direction perpendicular to the axis), that is, the aspect ratio is 1.05 or more is determined as the drawn pearlite.

[0052] A value obtained by averaging the area ratios of the drawn pearlite obtained from the photograph of the structure in the surface layer region (a position of 50 μm from the surface) is determined as the area ratio of the drawn pearlite in the surface layer region.

[0053] In addition, a value obtained by averaging the area ratios of the drawn pearlite obtained from the photographs of the structures at 1/4 × D and 1/2 × D is determined as the area ratio of the drawn pearlite in the internal region of the lengthwise-section.

<Variation in Hardness of Surface of Drawn steel wire>

[0054] It is considered that the hardness of the surface of the drawn steel wire affects the flow stress during torsional deformation. That is, when the hardness of the surface of the drawn steel wire varies, strain to be applied during applying torsional deformation is becomes uneven. It is considered that the unevenness may cause the delamination or the fracture at a small number of turns (decrease in number of turns). As a result of experiments and investigations by the inventors, it was found that in a case where a standard deviation (σ_{HV}) is used as variation in the Vickers hardness HV of the surface of the drawn steel wire, when σ_{HV} satisfies Expression (1) in response to the diameter (D [mm]) and the yield strength ($Rp_{0.2}$) of the drawn steel wire, the delamination and the decrease in the number of turns can be reliably suppressed when the torsional deformation is applied.

$$\sigma_{HV} < (-9500 \times \ln(D) + 30000) \times \exp(-0.003 \times Rp_{0.2}) \ldots (1)$$

[0055] Therefore, in the drawn steel wire according to this embodiment, the standard deviation σ_{HV} of the Vickers hardness HV on the surface of the drawn steel wire was specified to satisfy Expression (1). Here, it is preferable that the standard deviation of the Vickers hardness of the surface of the drawn steel wire is calculated from a hardness distribution obtained for an area of 500 mm^2 or more at a density of 1 points/mm^2 or more.

[0056] Specifically, the standard deviation σ_{HV} of the Vickers hardness of the surface of the drawn steel wire can be obtained by the following method.

[0057] That is, using a portable Rockwell hardness tester, an indenter is vertically pressed against the surface of the drawn steel wire under a load of 5 kgf, and the hardness is measured. At this time, indentation of 800 points or more is performed at intervals of 1 mm or less in the circumferential direction and the longitudinal direction of the drawn steel wire. The obtained hardness is converted into Vickers hardness, and the standard deviation (σ_{HV}) is obtained on the basis of the converted value.

[0058] In this embodiment, when the hardness is in terms of Rockwell hardness, the resolution of the numerical values of the variation is low. Therefore, a value converted into Vickers hardness using a conversion table is used.

[0059] Regarding zinc plating performed on the drawn steel wire, after a galvanized layer is peeled off by dipping the drawn steel wire in hydrochloric acid containing an inhibitor, the variation in the hardness may be measured in the above-described manner.

<Tensile Strength>

[0060] Delamination tends to occur in a high strength drawn steel wire having a tensile strength TS of 1770 MPa or more. Therefore, in this embodiment, a high strength drawn steel wire having a tensile strength TS of 1770 MPa or more is targeted. The upper limit of the tensile strength of the drawn steel wire according to this embodiment is not particularly limited. However, from the viewpoint of ease of production, the upper limit of the tensile strength may be about 2450 MPa.

<Torsional property of Drawn steel wire>

[0061] The drawn steel wire according to this embodiment aims for not occurring delamination and a number of turns of 20 times or more as the torsional property.

[0062] The torsional property of the drawn steel wire is obtained by conducting a torsion test in which both ends of the drawn steel wire are chucked and one side thereof is rotated, and measuring the number of turns and the torque. The distance between grips in the torsion test is set to $100 \times D$ (D is the wire diameter [mm]), and the torsion speed is set to 20 rpm.

[0063] As shown in FIG. 3, when longitudinal cracks called delamination is occurred, the torque is decreased. Therefore, occurring or not occurring the delamination can be determined by measuring the torque. In addition, the delamination can be confirmed from the form of the fractured surface.

[0064] In this embodiment, the number of turns until the delamination occurs, or in a case where fracture occurs without delamination, the number of turns until the fracture is used as the number of turns.

[0065] The diameter (wire diameter) of the drawn steel wire according to this embodiment is not particularly limited, and may be determined as appropriate according to the product application, standards, and the like. A typical diameter is about 1.5 mm to 7.0 mm.

[0066] Furthermore, the drawn steel wire according to this embodiment may be obtained by coating the surface of a high carbon drawn steel wire having the chemical composition, metallographic structure, and surface hardness distribution as described above with one or more metals of Zn, Al, Cu, Sn, Mg, and Si. That is, the drawn steel wire may be a coated drawn steel wire having a coating layer including one or more of Zn, Al, Cu, Sn, Mg, and Si on the surface of the drawn steel wire according to this embodiment. The coating layer may also be a plating layer.

[0067] A drawn steel wire used for a bridge cable, a drawn steel wire for prestressed concrete, and the like is subjected to zinc plating on the surface for use in many cases, and a drawn steel wire used for power applications such as aluminium conductors steel reinforced (ACSR) is used in a state in which the surface is coated with Al, Cu, or the like in many cases.

<Production Method>

[0068] In order to produce the drawn steel wire according to this embodiment, a production method including, for example, the following steps may be applied using steel that satisfies the above described conditions of the chemical composition as a material.

[0069] As long as each condition of the chemical composition or the metallographic structure of the drawn steel wire, and variation in the hardness of the surface of the drawn steel wire is in a range specified as above, an effect can be obtained regardless of the production method. Therefore, in a case where a drawn steel wire in which each condition of the chemical composition, metallographic structure, and variation in the hardness of the surface of the drawn steel wire is within the range specified as above is obtained by applying a process other than the process exemplified as follows, the drawn steel wire naturally corresponds to the drawn steel wire according to this embodiment.

[0070] First, steel having the chemical composition as described above is subjected to casting and blooming by a known method, thereby producing a steel piece. Thereafter, the steel piece is heated to 1000°C or higher and 1130°C or lower. The heating temperature is preferably set to 1000°C or higher in order to complete austenitizing. In addition, the heating temperature is preferably 1130°C or less, and more preferably 1100°C or less in order to suppress coarsening and duplex grain formation of austenite grains. In addition, the holding time after the predetermined heating temperature is reached is preferably shorter than 30 minutes in order to prevent promotion of decarburization of the surface layer and to suppress duplex grain formation of austenite grains.

[0071] A hot rolled steel is obtained by performing rough rolling and finish rolling on the steel piece after the heating. At this time, the temperature of the finish rolling (finish temperature) is adjusted in a range of 850°C to 980°C. When the finish rolling temperature is lower than 850°C, austenite grains are excessively refined and a pearlitic transformation becomes uneven. On the other hand, when the finish rolling temperature exceeds 980°C, it is difficult to control the austenite grains in a subsequent cooling process. In addition, the rolling reduction during the finish rolling is preferably 35% or more in terms of cumulative rolling reduction in order to control the austenite grains together with cooling process after winding process, which will be described later.

[0072] The hot rolled steel after the hot rolling is held for 15 minutes or longer at a temperature of not lower than 800°C, and the austenite grains are adjusted by sufficiently recrystallizing the austenite grains.

[0073] Next, the hot rolled steel after holding is directly dipped into a molten salt and is held at a temperature of 480°C or higher and 580°C or lower. Alternatively, the hot rolled steel is cooled to about room temperature by air blast cooling, thereafter heated to a temperature of the A3 point or higher (austenite region), and then dipped into molten lead at 480°C or higher and 600°C or lower. The A3 point of the steel can be obtained by a regression equation described in a known document, for example, "Lectures, Modern Metallurgy, Materials Vol. 4, Ferrous Materials" p.43 and the like.

[0074] The hot rolled steel dipped into the molten salt or molten lead is wire drawn to produce a drawn steel wire having a predetermined diameter. In order to control variation in the hardness of the surface layer of the drawn steel wire during wire drawing, the final pass of the wire drawing at which the strength is maximized is important. Specifically, it is effective to perform, as the final pass of the wire drawing, skin pass wire drawing at a wire drawing rate of 5 m/min to 30 m/min, and preferably 5 m/min to 25 m/min and at a reduction of area of 2.0% to 10.0%.

[0075] When the wire drawing rate exceeds 30 m/min, heat generation due to friction is increased, and thus the temperature of the drawn steel wire is increased. As a result, there is concern that σ_{HV} may be increased. On the other hand, when the wire drawing rate is less than 5 m/min, the amount of a lubricant pulled is decreased. When the amount of the lubricant pulled is decreased, there is concern that seizure may occur or the deformation heating amount may be increased, and the temperature of the wire rod may be increased, resulting in an increase in σ_{HV}.

[0076] Furthermore, when the reduction of area of the final pass (skin pass wire drawing) exceeds 10.0%, the effect of suppressing variation in the hardness cannot be sufficiently obtained. On the other hand, when the reduction of area is less than 2.0%, it is difficult to uniformly process the surface.

[0077] After the wire drawing, hot dip galvanizing or blueing, a heat stretching treatment, and the like may be performed as necessary.

[Examples]

[0078] Next, examples of the present invention will be described. The conditions shown in the examples are merely examples adopted for confirming the feasibility and effect of the present invention, and the present invention is not limited to these conditions. The present invention may adopt various conditions without departing from the gist of the present invention and as long as the object of the present invention is achieved.

[0079] Steel pieces having chemical compositions of kinds of steel A to T shown in Table 1 were subjected to heating, rolling, heat treatments, and wire drawing under conditions shown in Table 2 to produce drawn steel wires. In the tables, DLP indicates direct patenting (direct in-line patenting) with molten salt after rolling, and LP indicates lead patenting. Holding time of Table 2 indicates a holding time at 800°C or higher.

[Table 1]

Kind of steel	Chemical composition (mass%) Remainder: Fe and impurities													
	C	Si	Mn	P	S	Ti	Al	Cr	V	Nb	Mo	W	N	B
A	0.76	0.25	0.77	0.010	0.006	0.010	-	-	-	-	-	-	0.0031	-
B	0.77	0.28	0.30	0.011	0.008	-	0.052	-	-	-	0.06	-	0.0028	-
C	0.82	0.21	0.30	0.007	0.005	-	-	-	-	-	-	-	0.0043	-
D	0.82	0.22	0.75	0.009	0.006	-	0.030	-	-	-	-	-	0.0039	-
E	0.82	0.95	0.75	0.008	0.008	-	0.035	-	-	-	-	-	0.0048	-
F	0.83	0.68	0.88	0.010	0.005	-	0.035	-	-	0.020	-	-	0.0040	-
G	0.83	0.15	0.95	0.007	0.006	-	0.033	-	0.050	-	-	-	0.0038	-
H	0.85	1.30	0.20	0.012	0.009	-	0.044	0.25	-	-	-	0.09	0.0022	-
1	0.87	0.92	0.71	0.008	0.004	0.013	0.032	0.08	-	-	-	-	0.0038	-
J	0.92	0.23	0.70	0.008	0.004	0.013	0.032	-	-	-	-	-	0.0038	0.0010
K	0.92	1.20	0.35	0.010	0.006	0.016	0.028	0.26	-	-	-	-	0.0032	-
L	0.92	1.23	0.30	0.010	0.008	0.026	0.025	0.29	-	-	-	-	0.0035	0.0010
M	0.97	0.24	0.69	0.006	0.004	0.008	0.028	0.05	-	-	-	-	0.0031	-
N	0.97	1.25	0.32	0.012	0.007	0.018	0.035	0.27	-	-	-	-	0.0024	0.0015
O	0.99	0.90	0.35	0.010	0.005	-	0.035	0.10	0.060	-	-	-	0.0049	-
P	1.02	0.65	0.75	0.009	0.006	0.011	0.030	0.24	-	0.015	0.06	-	0.0030	0.0010
Q	1.09	1.10	0.40	0.010	0.008	0.010	-	0.05	-	-	-	-	0.0040	-
R	0.65	0.90	0.72	0.008	0.002	0.008	-	-	-	-	-	-	0.0035	-
S	0.93	0.21	0.66	0.005	0.006	-	0.035	-	-	-	-	-	0.0100	-
T	1.02	1.50	0.75	0.010	0.007	-	0.032	-	-	-	-	-	0.0020	-

[Table 2]

No.	Kind of steel	Production conditions												
		Steel piece heating		Hot rolling			Heat treatment				Cold working			
												Final pass		
		Temperature [°C]	Time [min]	Cumulative finish rolling reduction [%]	Finish temperature [°C]	Wire diameter [mm]	Holding time after finish rolling [sec]	Heat treatment	Re-heating temperature [°C]	Solvent temperature [°C]	Drawn steel wire diameter [mm]	Wire drawing rate [m/min]	Reduction of area [%]	Post-treatment
1	A	1100	20	35	900	13	20	DLP	-	550	4.0	20	7.1	Blueing
2	A	1100	20	35	900	13	20	LP	900	580	4.0	20	7.1	Blueing
3	B	1130	20	50	920	11	20	DLP	-	550	32	20	8.8	Zinc plating
4	C	1080	15	35	860	14	16	DLP	-	520	5.0	20	7.5	Blueing
5	D	1130	10	60	920	5.5	16	DLP	-	550	1.8	28	8.3	-
6	E	1080	15	40	900	11	20	DLP	-	550	5.2	20	7.3	Zinc plating
7	E	1080	15	40	900	11	20	LP	900	575	5.2	20	7.3	Zinc plating
8	F	1100	10	45	900	8	16	DLP	-	550	2.8	20	6.8	Blueing
9	G	1130	25	60	900	8	16	DLP	-	575	2.8	20	6.8	Zinc plating
10	H	1080	25	40	850	12	16	DLP	-	550	4.5	20	8.3	Zinc plating
11	I	1080	15	35	860	14	16	DLP	-	550	5.4	20	7.0	Zinc plating
12	J	1080	15	40	900	13	20	DLP	-	550	5.0	20	7.5	-
13	K	1080	20	35	860	12	16	DLP	-	550	5.0	20	7.5	Zinc plating
14	L	1100	20	35	900	14	16	DLP	-	550	7.0	20	8.1	Zinc plating

(continued)

No.	Kind of steel	Production conditions												
		Steel piece heating		Hot rolling			Heat treatment				Cold working			
		Temperature [°C]	Time [min]	Cumulative finish rolling reduction [%]	Finish temperature [°C]	Wire diameter [mm]	Holding time after finish rolling [sec]	Heat treatment	Re-heating temperature [°C]	Solvent temperature [°C]	Drawn steel wire diameter [mm]	Final pass		Post-treatment
												Wire drawing rate [m/min]	Reduction of area [%]	
15	M	1130	25	45	900	9	16	DLP	-	550	3.0	20	9.3	Zinc plating
16	N	1100	15	35	900	14	16	DLP	-	550	7.0	20	8.1	Zinc plating
17	N	1100	15	35	900	14	16	DLP	-	550	7.0	20	8.1	-
18	N	1100	15	35	900	14	16	DLP	-	550	5.4	20	7.0	Zinc plating
19	N	1100	15	45	900	12	20	DLP	-	550	5.0	20	7.5	Blueing
20	O	1100	15	45	900	12	20	DLP	-	550	5.0	20	7.5	-
21	P	1080	15	35	900	12	20	DLP	-	550	5.2	20	5.5	Zinc plating
22	Q	1080	15	35	900	16	20	DLP	-	550	7.0	20	8.1	-
x1	A	1100	20	35	900	13	20	DLP	-	550	4.0	120	7.1	Blueing
x2	D	1130	10	60	920	5.5	16	DLP	-	550	1.8	120	8.3	-
x3	F	1100	10	45	900	8	16	DLP	-	550	2.8	20	16.3	Blueing
x4	G	1130	25	60	900	8	16	DLP	-	575	2.8	120	6.8	Zinc plating
x5	H	1080	25	40	850	12	16	DLP	-	550	4.5	120	8.3	Zinc plating
x6	I	1080	60	35	860	14	16	DLP	-	550	5.4	20	5.6	Zinc plating

(continued)

No.	Kind of steel	Production conditions												
		Steel piece heating		Hot rolling			Heat treatment				Cold working			
		Temperature [°C]	Time [min]	Cumulative finish rolling reduction [%]	Finish temperature [°C]	Wire diameter [mm]	Holding time after finish rolling [sec]	Heat treatment	Re-heating temperature [°C]	Solvent temperature [°C]	Drawn steel wire diameter [mm]	Final pass		Post-treatment
												Wire drawing rate [m/min]	Reduction of area [%]	
x7	I	1160	25	35	860	14	16	DLP	-	550	5.4	20	5.6	Zinc plating
x8	K	1080	20	35	860	12	16	DLP		550	4.6	40	4.2	Blueing
x9	M	1130	25	45	900	9	16	DLP	-	550	3.0	120	9.3	Zinc plating
x10	N	1100	20	10	900	14	24	DLP	-	550	7.0	20	8.1	Zinc plating
x11	N	1130	15	35	1000	14	16	DLP	-	550	7.0	20	8.1	Zinc plating
x12	N	1180	25	35	900	14	16	DLP	-	550	7.0	20	8.1	Zinc plating
x13	N	1100	15	45	900	12	20	DLP	-	550	5.0	120	7.5	Blueing
x14	N	1100	15	45	900	12	20	DLP	-	550	5.0	20	14.3	Blueing
x15	N	1100	15	45	900	12	20	DLP	-	550	5.0	120	14.3	Blueing
x16	R	1080	20	35	900	16	20	DLP	-	550	5.0	20	7.5	Blueing
x17	S	1080	15	40	900	14	16	DLP	-	550	5.0	20	5.2	-
x18	T	1130	15	35	900	14	16	DLP	-	550	5.4	20	5.6	Zinc plating
x19	N	1220	120	35	900	14	16	DLP	-	550	7.0	20	8.1	Zinc plating

[0080] On the obtained drawn steel wires, a tensile test, metallographic structure observation, surface hardness measurement, and a torsion test were conducted.

<Tensile Test>

[0081] According to the method described in JIS G 3521, the tensile test of the drawn steel wire was conducted under conditions of a distance between grips of 200 mm, a distance between gauges of 50 mm, a tensile rate of 10 mm/min, and the tensile strength TS and the yield strength YS (0.2% proof stress $Rp_{0.2}$) were measured.

<Metallographic Structure Observation>

[0082] At the surface layer region of the lengthwise-section (a position at a depth of 50 μm from the surface), 1/4 × D (a position at a 1/4 depth of the diameter D of the drawn steel wire from the surface), and 1/2 × D (a position at a 1/2 depth of the diameter D of the drawn steel wire from the surface), five visual fields were observed at a magnification of 2,000-fold using an optical microscope, and the photographs of the structures in the observed visual fields were taken. Image analysis was performed by marking the non-pearlite structure of the taken photograph and the area ratio of drawn pearlite was measured. At this time, a region composed of only ferrite and a structure in which cementite was coarsely scattered in ferrite were determined as the non-pearlite structure. In addition, pearlite in which the ratio between the maximum length in the axial direction of pearlite grains and the maximum thickness in the direction perpendicular thereto (maximum length in the axial direction / maximum thickness in the direction perpendicular to the axis), that is, the aspect ratio was 1.05 or more was determined as the drawn pearlite.

[0083] A value obtained by averaging the area ratios of the drawn pearlite of each of the visual fields obtained from the photograph of the structure in the surface layer region was determined as the area ratio of the drawn pearlite in the surface layer region of the lengthwise-section.

[0084] In addition, a value obtained by averaging the area ratios of the pearlite obtained from the photographs of the structures at 1/4 × D and 1/2 × D was determined as the area ratio of the drawn pearlite in the internal region of the lengthwise-section.

<Surface Hardness Measurement>

[0085] The hardness of the surface of the drawn steel wire was measured by a portable Rockwell hardness tester. An indenter was vertically driven with a load of 5 kgf against the surface of the drawn steel wire, and the hardness was measured. The hardness was obtained by performing indentation of 800 points or more at intervals of 1 mm or less in the circumferential direction and the longitudinal direction of the drawn steel wire. FIG. 1 shows an example of an external appearance photograph of the drawn steel wire surface of the drawn steel wire driven by the indenter.

[0086] Each of hardnesses obtained was converted into a Vickers hardness, and the standard deviation (σ_{HV}) was obtained from the converted value.

[0087] From the value of the yield strength obtained by the tensile test and the wire diameter (diameter of the drawn steel wire), the threshold of the standard deviation corresponding to the right side of Expression (1) was obtained. Then, by comparing these values, variation in the hardness of the surface of the drawn steel wire was evaluated.

[0088] In addition, for the drawn steel wire subjected to zinc plating, the plating layer was peeled off by dipping the drawn steel wire in hydrochloric acid containing an inhibitor, and the variation in the hardness was measured in the above-described manner.

<Torsion Test>

[0089] Evaluation of the torsional property of each of the drawn steel wires was performed on the basis of the torsion test method of JIS G 3521 by conducting a torsion test in which both ends of the drawn steel wire were chucked and one side thereof was rotated, and measuring the number of turns and the torque. The form of the fractured surface was checked. In the torsion test, the distance between grips was set to 100 × D (D is the wire diameter [mm]), and the torsion speed was set to 20 rpm.

[0090] The number of turns until the delamination occurred, or in a case where fracture occurred without delamination, the number of turns until the fracture was used as the number of turns. In a case where the number of turns was 20 times or more without delamination, excellent torsional property was determined.

[0091] Table 3 shows the properties of each of the drawn steel wires obtained.

[Table 3]

No.	Properties of drawn steel wire									Division
	Tensile properties			Metallosraphic structure		Surface hardness		Torsional property		
	TS [MPa]	YS [MPa]	Yield ratio	Area ratio of drawn pearlite in surface layer region [%]	Area ratio of drawn pearlite in internal region	σ_{HV} [HV]	σ_{HV} threshold [HV]	Number of turns (Times)	Delamination	
1	2200	1860	0.85	95	98	60	63.5	25	Not occurred	Present Invention
2	2180	1870	0.86	92	98	55	61.6	30	Not occurred	
3	1980	1750	0.88	90	99	45	99.4	24	Not occurred	
4	2020	1720	0.85	93	96	55	84.5	29	Not occurred	
5	2240	1690	0.75	95	99	70	153.4	31	Not occurred	
6	1830	1710	0.93	85	98	48	84.8	27	Not occurred	
7	1880	1730	0.92	80	99	56	79.9	28	Not occurred	
8	2200	1880	0.85	90	97	70	71.8	29	Not occurred	
9	2060	1860	0.90	91	98	60	76.3	26	Not occurred	
10	2160	1900	0.88	78	95	48	52.6	21	Not occurred	
11	2020	1870	0.93	82	97	42	51.2	24	Not occurred	
12	2120	1650	0.78	95	99	85	104.2	28	Not occurred	
13	2100	1860	0.89	88	95	52	55.5	22	Not occurred	
14	1960	1770	0.90	78	96	45	56.9	20	Not occurred	
15	2120	1880	0.89	95	98	49	69.5	24	Not occurred	
16	2060	1860	0.90	80	97	42	43.4	21	Not occurred	
17	2090	1750	0.84	80	97	53	60.4	28	Not occurred	
18	2210	1980	090	80	97	35	36.8	21	Not occurred	
19	2250	1960	0.87	85	97	38	41.1	22	Not occurred	
20	2320	1860	0.80	82	97	51	55.5	27	Not occurred	
21	2150	1880	0.87	92	96	45	50.9	23	Not occurred	
22	2220	1780	0.80	95	98	53	55.2	26	Not occurred	

(continued)

No.	Properties of drawn steel wire									Division
	Tensile properties			Metallosraphic structure		Surface hardness		Torsional property		
	TS [MPa]	YS [MPa]	Yield ratio	Area ratio of drawn pearlite in surface layer region [%]	Area ratio of drawn pearlite in internal region	σ_{HV} [HV]	σ_{HV} threshold [HV]	Number of turns (Times)	Delamination	
x1	2230	1940	0.87	95	98	<u>62</u>	49.9	12	Occurred	Comparative Example
x2	2280	1850	0.81	95	99	<u>105</u>	94.9	10	Occurred	
x3	2200	1880	0.85	90	97	<u>78</u>	71.8	14	Occurred	
x4	2050	1900	0.90	91	98	<u>85</u>	76.3	8	Occurred	
x5	2140	1920	0.88	78	95	<u>67</u>	52.6	5	Occurred	
x6	2010	1870	0.93	<u>66</u>	94	<u>55</u>	51.2	8	Occurred	
x7	2040	1900	0.93	<u>69</u>	97	<u>58</u>	46.8	5	Occurred	
x8	2250	2000	0.89	88	95	<u>45</u>	38.4	16	Not occurred	
x9	2110	1890	0.89	95	98	<u>72</u>	69.5	18	Occurred	
x10	2030	1880	0.93	82	96	<u>58</u>	40.9	4	Occurred	
x11	2060	1900	0.92	85	95	<u>48</u>	38.5	7	Occurred	
x12	2010	1840	0.92	<u>68</u>	98	<u>67</u>	46.1	3	Occurred	
x13	2300	2040	0.87	85	97	<u>72</u>	32.3	10	Occurred	
x14	2250	1990	0.87	85	97	<u>40</u>	37.6	15	Occurred	
x15	2280	2010	0.87	85	97	<u>45</u>	35.4	12	Occurred	
x16	2060	1850	0.90	<u>65</u>	<u>88</u>	<u>65</u>	57.2	11	Occurred	
x17	2190	1750	0.80	95	97	<u>88</u>	77.2	13	Occurred	
x18	2240	2050	0.92	<u>55</u>	<u>89</u>	<u>47</u>	29.8	4	Occurred	
x19	2010	1830	0.91	<u>30</u>	97	45	47.5	15	Occurred	

[0092] Test Nos. 1 to 22 shown in Tables 1 to 3 are examples (present invention examples) of the drawn steel wires which satisfy each of the conditions specified in the present invention, and it was confirmed that all the examples were excellent in torsional property.

[0093] On the other hand, in Test Nos. x1 to x19 of comparative examples, production conditions such as the chemical compositions or the wire drawing conditions were not appropriate, and conditions for the metallographic structure and/or the variation in the surface hardness deviated from the ranges specified in the present invention. As a result, good torsional property was not obtained.

[0094] FIG. 2 shows the relationship between the σ_{HV} threshold (the value on the right side of (1) described above) and the yield strength, and twisting properties of the drawn steel wires having a wire diameter in a range of 5.0 mm to 5.4 mm among the present invention examples and the comparative examples in the examples. In FIG. 2, an O mark indicates that delamination had not occurred and the number of turns was 20 times or more, and an X mark indicates that the number of turns was less than 20 times. It is apparent from FIG. 2 that high strength and excellent torsional property can be obtained within the ranges specified in the present invention.

[0095] While the preferred embodiments and examples of the present invention have been described above, these embodiments and examples are merely examples within the scope of the gist of the present invention, and additions, omissions, substitutions, and other changes regarding the configuration are possible without departing from the gist of the present invention. That is, the present invention is not limited by the above description but is limited only by the claims, and appropriate changes can be made within the scope thereof.

Claims

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

   C: 0.75% to 1.10%,
   Si: 0.10% to 1.40%,
   Mn: 0.10% to 1.0%,
   Al: 0% to 0.10%,
   Ti: 0% to 0.10%,
   Cr: 0% to 0.60%,
   V: 0% to 0.10%,
   Nb: 0% to 0.10%,
   Mo: 0% to 0.20%,
   W: 0% to 0.50%,
   B: 0% to 0.0030%,
   N: limited to 0.0060% or less,
   P: limited to 0.030% or less,
   S: limited to 0.030% or less, and
   a remainder including Fe and impurities; wherein
   in a region of the drawn steel wire that is closer to an axis line than a depth of 100 μm from a surface of the drawn steel wire in a lengthwise-section that includes the axis line of the drawn steel wire, a metallographic structure includes 90% or more of a drawn pearlite by an area ratio;
   in a region of the drawn steel wire that is the depth of 100 μm from the surface of the drawn steel wire in the lengthwise-section, the metallographic structure includes 70% or more of the drawn pearlite by the area ratio;
   when D in units of millimeters represents a diameter of the drawn steel wire, σ_{HV} represents a standard deviation of a Vickers hardness of the surface of the drawn steel wire, and $Rp_{0.2}$ represents a yield strength of the drawn steel wire, Expression (1) is satisfied; and
   a tensile strength of the drawn steel wire is 1770 MPa or higher.

$$\sigma_{HV} < (-9500 \times \ln(D) + 30000) \times \exp(-0.003 \times Rp_{0.2}) \ldots (1)$$

2. The drawn steel wire according to claim 1, wherein the chemical composition includes, by mass%, at least one selected from the group consisting of

   Al: 0.001% to 0.10%,
   Ti: 0.001% to 0.10%,
   Cr: more than 0% and 0.60% or less,

V: more than 0% and 0.10% or less,
Nb: more than 0% and 0.10% or less,
Mo: more than 0% and 0.20% or less,
W: more than 0% and 0.50% or less, and
B: more than 0% and 0.0030% or less.

3. The drawn steel wire according to claim 1 or 2, wherein a coating layer including one or more of Zn, Al, Cu, Sn, Mg, and Si on the surface of the drawn steel wire is provided.

FIG. 1

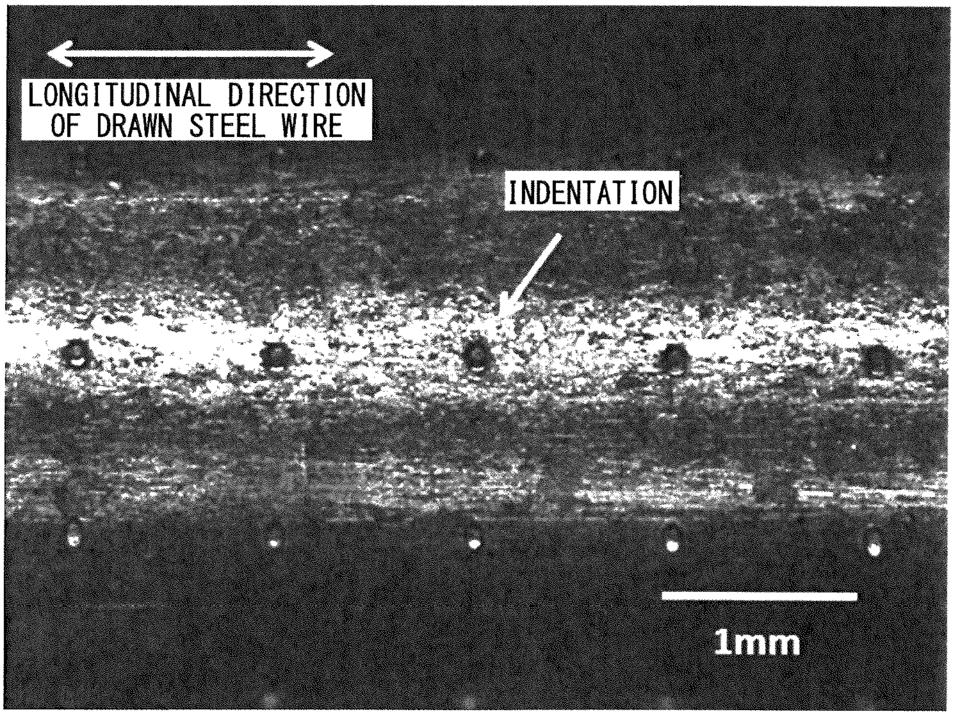

LONGITUDINAL DIRECTION
OF DRAWN STEEL WIRE
INDENTATION
1mm

FIG. 2

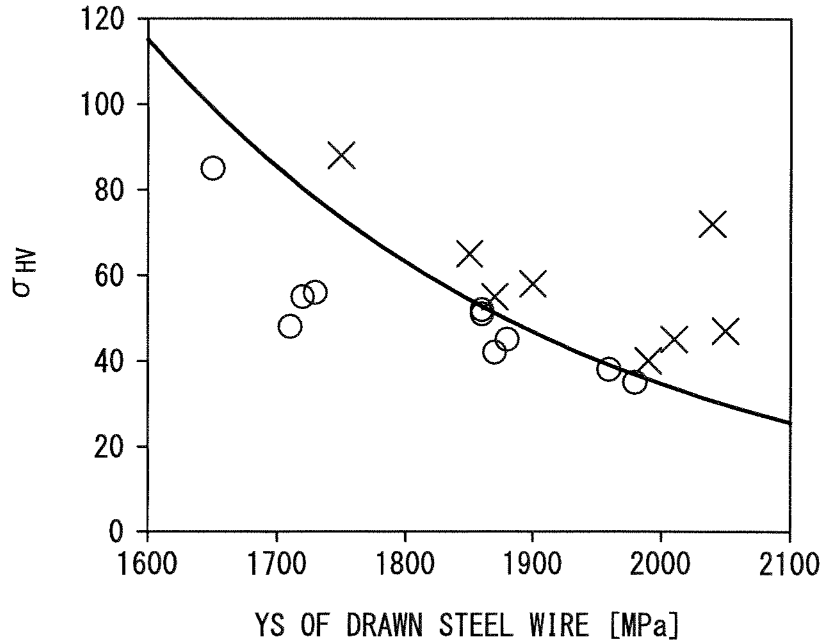
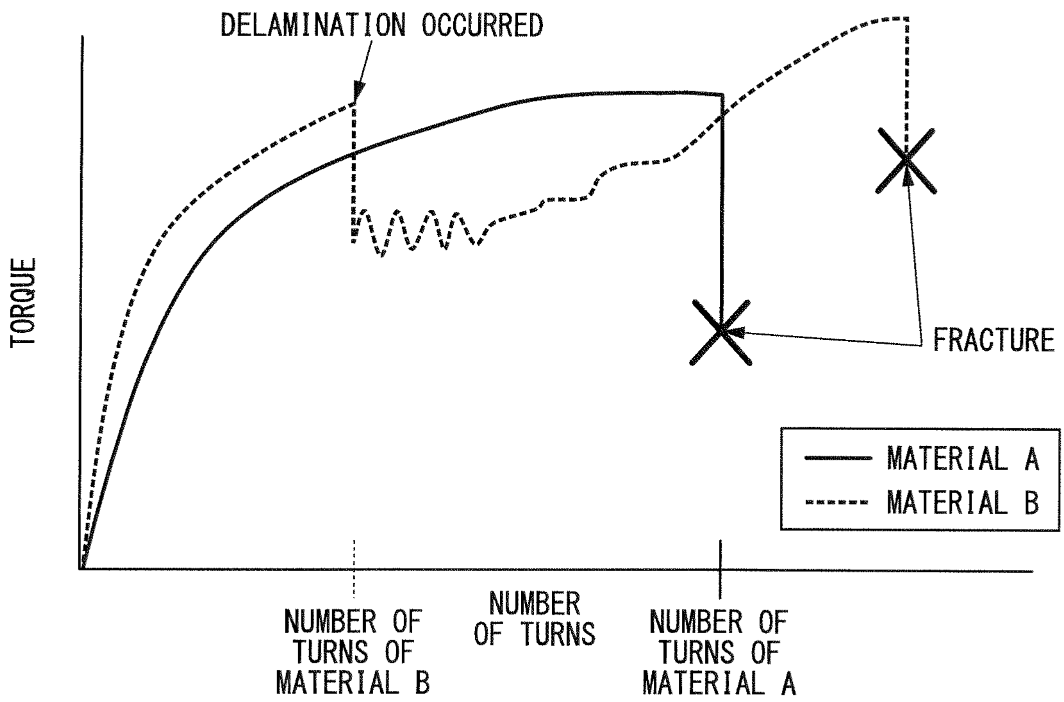

120
100
80
60
40
20
0
σ_{HV}
1600
1700
1800
1900
2000
2100
YS OF DRAWN STEEL WIRE [MPa]

FIG. 3


DELAMINATION OCCURRED
TORQUE
FRACTURE
MATERIAL A
MATERIAL B
NUMBER OF TURNS OF MATERIAL B
NUMBER OF TURNS
NUMBER OF TURNS OF MATERIAL A

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2017/025782

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C22C38/32*(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-C21D8/08

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	1996-2017
Kokai Jitsuyo Shinan Koho	1971-2017	Toroku Jitsuyo Shinan Koho	1994-2017

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2015/186801 A1 (Nippon Steel & Sumitomo Metal Corp.), 10 December 2015 (10.12.2015), & KR 10-2017-0002541 A & CN 106414786 A	1-3
A	JP 2013-249492 A (Nippon Steel & Sumitomo Metal Corp.), 12 December 2013 (12.12.2013), (Family: none)	1-3
A	WO 2010/150537 A1 (Nippon Steel Corp.), 29 December 2010 (29.12.2010), & US 2012/0070687 A1 & EP 2447389 A1 & KR 10-2011-0036855 A & CN 102137949 A	1-3

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 September 2017 (29.09.17)	10 October 2017 (10.10.17)

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

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/025782

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2008/093466 A1 (Nippon Steel Corp.), 07 August 2008 (07.08.2008), & US 2010/0239884 A1 & EP 2062991 A1 & CN 101426943 A & KR 10-2009-0007707 A	1-3
A	JP 2005-163082 A (Kobe Steel, Ltd.), 23 June 2005 (23.06.2005), (Family: none)	1-3
A	US 2004/0118486 A1 (THE GOODYEAR TIRE & RUBBER CO.), 24 June 2004 (24.06.2004), & EP 1433868 A1 & BR 305998 A	1-3

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2016139744 A **[0002]**
- JP 3984393 B **[0011]**
- JP 3036393 B **[0011]**
- JP 4377715 B **[0011]**

Non-patent literature cited in the description

- *Lectures, Modern Metallurgy, Materials Vol. 4, Ferrous Materials,* vol. 4, 43 **[0073]**