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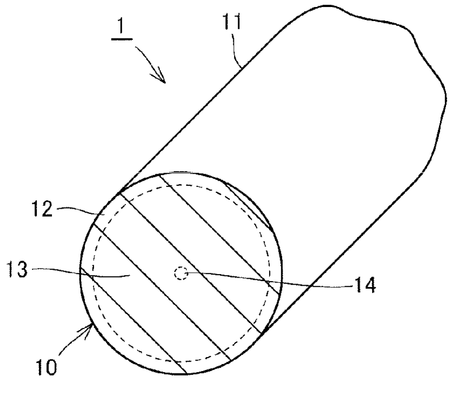
(54) **STEEL SPRING WIRE, SPRING, STEEL SPRING WIRE PRODUCTION METHOD AND SPRING PRODUCTION METHOD**

(57) A steel wire for a spring is formed of a steel containing from 0.5% by mass to 0.8% by mass of carbon, from 1.0% by mass to 2.5% by mass of silicon, from 0.2% by mass to 1.0% by mass of manganese, and from 0.5% by mass to 2.5% by mass of chromium, the balance being iron and incidental impurities. The steel has a tempered martensite structure. The hardness of a surface region that is a region within 10 μm from an outer surface is from more than 0 HV to 50 HV higher than the hardness of a region other than the surface region.

FIG. 1

FIG.1



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Description

Technical Field

[0001] The present invention relates to steel wires for springs, to springs, to methods for manufacturing steel wires for springs, and to methods for manufacturing springs.

[0002] The present application claims priority to Japanese Patent Application No. 2016-139668, filed on Jul. 14, 2016, and Japanese Patent Application No. 2017-038665, filed on Mar. 1, 2017, the entire contents of which are incorporated herein by reference.

Background Art

[0003] As a method for improving the fatigue strength of springs while reducing the likelihood of fractures during coiling, there is proposed a technique involving drawing a quenched and tempered wire at a reduction of area of 5% to 25%. Thus, the likelihood of fractures during coiling is reduced, and the yield stress of the spring is increased by heat treatment after coiling to obtain a spring with excellent fatigue strength (see, for example, Japanese Unexamined Patent Application Publication No. 2012-52218 (PTL 1)).

Citation List

Patent Literature

[0004] PTL 1: Japanese Unexamined Patent Application Publication No. 2012-52218

Summary of Invention

[0005] A steel wire for a spring according to the present invention is formed of a steel containing from 0.5% by mass to 0.8% by mass of carbon, from 1.0% by mass to 2.5% by mass of silicon, from 0.2% by mass to 1.0% by mass of manganese, and from 0.5% by mass to 2.5% by mass of chromium, the balance being iron and incidental impurities. The steel has a tempered martensite structure. The hardness of a surface region that is a region within 10 μm from an outer surface is from more than 0 HV to 50 HV higher than the hardness of a region other than the surface region.

[0006] A method for manufacturing a steel wire for a spring according to a first aspect of the present invention includes the steps of providing a starting wire material containing from 0.5% by mass to 0.8% by mass of carbon, from 1.0% by mass to 2.5% by mass of silicon, from 0.2% by mass to 1.0% by mass of manganese, and from 0.5% by mass to 2.5% by mass of chromium, the balance being iron and incidental impurities; subjecting the starting wire material to first drawing; subjecting to carburizing treatment the starting wire material subjected to the first drawing such that the carbon concentration of a region including a surface of the starting wire material is from more than 0% by mass to 0.05% by mass higher than the carbon concentration of the interior thereof; and subjecting to quenching and tempering treatment the starting wire material subjected to the carburizing treatment.

[0007] A method for manufacturing a steel wire for a spring according to a second aspect of the present invention includes the steps of providing a starting wire material containing from 0.5% by mass to 0.8% by mass of carbon, from 1.0% by mass to 2.5% by mass of silicon, from 0.2% by mass to 1.0% by mass of manganese, and from 0.5% by mass to 2.5% by mass of chromium, the balance being iron and incidental impurities; subjecting the starting wire material to first drawing; subjecting to quenching and tempering treatment the starting wire material subjected to the first drawing; and subjecting to second drawing the starting wire material subjected to the quenching and tempering treatment. The second drawing is performed at a reduction of area of from 1% to less than 5%.

Brief Description of Drawings

[0008]

Figure 1 is a schematic view showing the structure of a steel wire for a spring.
Figure 2 is a schematic view showing the structure of a spring.
Figure 3 is a flowchart showing, in outline, a method for manufacturing a steel wire for a spring and a spring according to a first embodiment.
Figure 4 is a schematic view showing the structure of a starting wire material.
Figure 5 is a graph illustrating a carburizing step and a quenching and tempering step.
Figure 6 is a schematic sectional view illustrating a second drawing step.
Figure 7 is a flowchart showing, in outline, a method for manufacturing a steel wire for a spring and a spring according to a second embodiment. Description of Embodiments

[Technical Problem]

[0009] As discussed above, there is a need to achieve both improved fatigue strength and a reduced likelihood of fractures during coiling. Accordingly, an object of the present disclosure is to provide a steel wire for a spring, a spring, a method for manufacturing a steel wire for a spring, and a method for manufacturing a spring that can achieve improved fatigue strength with a reduced likelihood of fractures during coiling.

[Advantageous Effects of Disclosure]

[0010] The steel wire for a spring and the method for manufacturing a steel wire for a spring according to the present disclosure can achieve improved fatigue strength with a reduced likelihood of fractures during coiling.

[Description of Embodiments of Invention]

[0011] First, a list of embodiments of the present invention will be described. A steel wire for a spring according to the present application is formed of a steel containing from 0.5% by mass to 0.8% by mass of carbon (C), from 1.0% by mass to 2.5% by mass of silicon (Si), from 0.2% by mass to 1.0% by mass of manganese (Mn), and from 0.5% by mass to 2.5% by mass of chromium (Cr), the balance being iron and incidental impurities. The steel has a tempered martensite structure. The hardness of a surface region that is a region within 10 μm from an outer surface is from more than 0 HV to 50 HV higher than the hardness of a region other than the surface region.

[0012] According to research conducted by the inventors, a steel wire for a spring that can achieve improved fatigue strength with a reduced likelihood of fractures during coiling is obtained by slightly increasing the hardness of a steel wire formed of a steel having a suitable constituent composition and a tempered martensite structure only in an extremely thin surface region as compared to the interior. The steel used for the steel wire for a spring according to the present application has a constituent composition that can ensure the strength required of springs and a tempered martensite structure. The hardness of an extremely thin surface region that is within 10 μm from the outer surface (surface region) is set to be from more than 0 HV to 50 HV higher than the hardness of the region other than the surface region (interior region). Since the hardness is increased only in the surface region by 50 HV or less in this way, the steel wire for a spring according to the present application can achieve improved fatigue strength with a reduced likelihood of fractures during coiling.

[0013] Here, the reasons for limiting the constituent composition of the steel forming the steel wire for a spring to the ranges mentioned above will be described herein.

Carbon: from 0.5% by mass to 0.8% by mass

[0014] Carbon is an element that greatly affects the strength of a steel having a tempered martensite structure. To achieve sufficient strength for use as a steel wire for a spring, it is necessary that the carbon content be 0.5% by mass or more. On the other hand, high carbon contents would result in decreased toughness and thus decreased workability during coiling and drawing. To ensure sufficient workability, it is necessary that the carbon content be 0.8% by mass or less. To further improve the strength, it is preferred that the carbon content be 0.6% by mass or more. To improve the toughness and facilitate working, it is preferred that the carbon content be 0.7% by mass or less.

Silicon: from 1.0% by mass to 2.5% by mass

[0015] Silicon has the property of reducing softening upon heating (softening resistance). To reduce softening during strain-removing heat treatment performed after the coiling of the steel wire for a spring, it is necessary that the silicon content be 1.0% by mass or more. On the other hand, the addition of excess silicon would decrease the toughness of the steel wire for a spring. To ensure sufficient toughness, it is necessary that the silicon content be 2.5% by mass or less. To further improve the resistance to softening upon heating, it is preferred that the silicon content be 1.3% by mass or more. To more reliably ensure sufficient toughness, it is preferred that the silicon content be 2.3% by mass or less.

Manganese: from 0.2% by mass to 1.0% by mass

[0016] Manganese is an element added as a deoxidizing agent in steel refining. To allow manganese to function as a deoxidizing agent, it is necessary that the manganese content be 0.2% by mass or more. On the other hand, the addition of excess manganese would result in the formation of a martensite structure upon cooling after heating. An unintentionally formed martensite structure would decrease workability during processes such as drawing. Accordingly, it is necessary that the manganese content be 1.0% by mass or less. To allow manganese to more reliably function as a deoxidizing agent, it is preferred that the manganese content be 0.3% by mass or more. To more reliably reduce unintentional formation of a martensite structure, it is preferred that the manganese content be 0.85% by mass or less.

Chromium: from 0.5% by mass to 2.5% by mass

[0017] Chromium contributes to reducing softening upon heating after quenching and tempering. To reliably produce this effect, it is necessary that the chromium content be 0.5% by mass or more. On the other hand, the addition of excess chromium would result in the formation of a martensite structure upon cooling after heating. An unintentionally formed martensite structure would decrease workability during processes such as drawing. Accordingly, it is necessary that the chromium content be 2.5% by mass or less. To more reliably reduce softening upon heating after quenching and tempering, it is preferred that the chromium content be 0.7% by mass or more. To more reliably reduce unintentional formation of a martensite structure, it is preferred that the chromium content be 1.5% by mass or less.

Incidental impurities

[0018] In the process of manufacturing the steel wire for a spring, impurities such as phosphorus (P), sulfur (S), and copper (Cu) are incidentally incorporated into the steel forming the steel wire for a spring. The presence of excess phosphorus and sulfur would cause grain boundary segregation and form inclusions, thus degrading the properties of the steel. Accordingly, the phosphorus and sulfur contents are each preferably 0.035% by mass or less, more preferably 0.025% by mass or less. Copper would decrease the hot workability of the steel. Accordingly, the copper content is preferably 0.2% by mass or less. The total incidental impurity content is preferably 1% by mass or less.

[0019] The steel wire for a spring may have a diameter of 15 mm or less. The steel wire for a spring according to the present application is suitable for use as a steel wire for a spring with such a wire diameter. If the steel wire for a spring has a non-circular cross-section perpendicular to the longitudinal direction, "diameter" as used herein means the diameter of a circle circumscribing the cross-section.

[0020] The carbon concentration of the surface region of the steel wire for a spring may be from more than 0% by mass to 0.05% by mass higher than the carbon concentration of the region other than the surface region. If the carbon content of the surface region is higher than the carbon content of the interior (the region other than the surface region), the hardness of the surface region can be easily made higher than the hardness of the interior.

[0021] The proportion of the {110} texture in the surface region of the steel wire for a spring may be from 5% to 35% higher than the proportion of the {110} texture in a central region that is a region within 10 μm from the center of gravity of a cross-section perpendicular to the longitudinal direction of the steel wire for a spring. This increases the elastic limit for shear stress. As a result, the fatigue strength and settling resistance of a spring manufactured from the steel wire for a spring can be improved.

[0022] If the proportion of the {110} texture in the surface region is 5% or more higher than the proportion of the {110} texture in the central region, the effect described above is clear. On the other hand, if the proportion of the {110} texture in the surface region is more than 35% higher than the proportion of the {110} texture in the central region, the steel wire for a spring would exhibit decreased workability during coiling. From the viewpoint of workability, it is preferred that the proportion of the {110} texture in the surface region be 30% or less higher than the proportion of the {110} texture in the central region. It is more preferred that the proportion of the {110} texture in the surface region be 15% or less higher than the proportion of the {110} texture in the central region. The proportion of the {110} texture in the central region is, for example, 3% or less.

[0023] The proportions of the {110} texture in the surface region and the central region can be measured, for example, as follows. The steel wire for a spring is first cut, and the cross-section is mechanically polished. The mechanically polished cross-sectional surface is then subjected to ion polishing with an ion beam, such as an argon ion beam, for removal of any surface region damaged by mechanical polishing to obtain an observation surface. The resulting observation surface is then subjected to crystal orientation measurement to measure the proportions of the {110} texture in the surface region and the central region, for example, by electron back-scatter diffraction (EBSD).

[0024] The steel wire for a spring may have a circularity of 3 μm or less in a cross-section perpendicular to the longitudinal direction. This stabilizes the properties of a spring manufactured from the steel wire for a spring.

[0025] The steel wire for a spring may have a variation in diameter of 1% or less per meter in a cross-section perpendicular to the longitudinal direction. This stabilizes the properties of a spring manufactured from the steel wire for a spring.

[0026] The steel forming the steel wire for a spring may further contain from 0.05% by mass to 0.5% by mass of vanadium. Vanadium contributes to reducing softening upon heating by forming fine carbides in the steel. To reliably produce this effect, vanadium may be added in an amount of 0.05% by mass or more. On the other hand, the addition of excess vanadium would decrease the toughness of the steel. To ensure sufficient toughness, vanadium is preferably added in an amount of 0.5% by mass or less, preferably 0.25% by mass or less.

[0027] A spring according to the present application is formed of the foregoing steel wire for a spring. Since the spring according to the present application is formed of the steel wire for a spring according to the present application, a spring that exhibits improved fatigue strength can be provided with a reduced likelihood of fractures during coiling.

[0028] The spring may have a surface with a nitrogen concentration of 300 ppm or less. The spring according to the present application exhibits sufficient fatigue strength without a treatment that increases the nitrogen concentration of the surface of the spring above such a range, for example, nitriding treatment.

[0029] A method for manufacturing a steel wire for a spring according to a first aspect of the present application includes the steps of providing a starting wire material containing from 0.5% by mass to 0.8% by mass of carbon, from 1.0% by mass to 2.5% by mass of silicon, from 0.2% by mass to 1.0% by mass of manganese, and from 0.5% by mass to 2.5% by mass of chromium, the balance being iron and incidental impurities; subjecting the starting wire material to first drawing; subjecting to carburizing treatment the starting wire material subjected to the first drawing such that the carbon concentration of a region including the surface of the starting wire material is from more than 0% by mass to 0.05% by mass higher than the carbon concentration of the interior thereof; and subjecting to quenching and tempering treatment the starting wire material subjected to the carburizing treatment.

[0030] In the method for manufacturing a steel wire for a spring according to the first aspect of the present application, the starting wire material having the foregoing suitable constituent composition is subjected to carburizing treatment to slightly increase the carbon concentration of the region including the surface, followed by quenching and tempering treatment. This allows the hardness of the steel wire for a spring, which is formed of a steel having a suitable constituent composition and a tempered martensite structure, to be slightly increased only in an extremely thin surface region as compared to the interior. As a result, the steel wire for a spring according to the present application can be easily manufactured such that the hardness of an extremely thin surface region that is within 10 μm from the outer surface (surface region) is set to be from more than 0 HV to 50 HV higher than the hardness of the region other than the surface region (interior region).

[0031] In the method for manufacturing a steel wire for a spring according to the first aspect, the step of subjecting to carburizing treatment the starting wire material subjected to the first drawing may include performing carburizing treatment by heating the starting wire material in an atmosphere whose composition is controlled to have a carbon potential (CP) value of from 0.5% by mass to 1.5% by mass. If the carburizing treatment is performed by gas carburizing in an atmosphere with a controlled CP value, the carbon concentration of the surface region becomes stable. As a result, the variation in the hardness of the surface region is reduced, and a steel wire for a spring can be easily manufactured such that the hardness of the surface region is from more than 0 HV to 50 HV higher than the hardness of the interior region.

[0032] The method for manufacturing a steel wire for a spring according to the first aspect may further include a step of subjecting to second drawing the starting wire material subjected to the quenching and tempering treatment. This improves the dimensional accuracy of the steel wire for a spring.

[0033] In the method for manufacturing a steel wire for a spring according to the first aspect, the second drawing may be performed at a reduction of area of from 1% to less than 5%. If the reduction of area is not less than 5%, it would be difficult to achieve an increase in hardness only in the extremely thin surface region since the hardness would also increase in the interior of the steel wire after drawing. If the reduction of area is set to less than 5% to achieve an increase in hardness only in the surface layer, the steel wire for a spring according to the present application can be more easily manufactured. If the reduction of area is 1% or more, an increase in hardness can be more reliably achieved in the extremely thin surface region after drawing.

[0034] A method for manufacturing a steel wire for a spring according to a second aspect of the present application includes the steps of providing a starting wire material containing from 0.5% by mass to 0.8% by mass of carbon, from 1.0% by mass to 2.5% by mass of silicon, from 0.2% by mass to 1.0% by mass of manganese, and from 0.5% by mass to 2.5% by mass of chromium, the balance being iron and incidental impurities; subjecting the starting wire material to first drawing; subjecting to quenching and tempering treatment the starting wire material subjected to the first drawing; and subjecting to second drawing the starting wire material subjected to the quenching and tempering treatment. The second drawing is performed at a reduction of area of from 1% to less than 5%.

[0035] In the method for manufacturing a steel wire for a spring according to the second aspect of the present application, the starting wire material having the foregoing suitable constituent composition is subjected to quenching and tempering treatment, followed by the second drawing at a reduction of area of from 1% to less than 5%. This allows the hardness of the steel wire for a spring, which is formed of a steel having a suitable constituent composition and a tempered martensite structure, to be slightly increased only in an extremely thin surface region as compared to the interior. As a result, the steel wire for a spring according to the present application can be easily manufactured such that the hardness of an extremely thin surface region that is within 10 μm from the outer surface (surface region) is set to be from more than 0 HV to 50 HV higher than the hardness of the region other than the surface region (interior region).

[0036] In the methods for manufacturing a steel wire for a spring, the second drawing may be performed while the starting wire material is heated to a temperature range from 25°C to 450°C. This forms a Cottrell atmosphere in the steel, thus increasing the strength of the steel wire for a spring. The second drawing may be performed while the starting wire material is heated to a temperature range from 150°C to 450°C.

[0037] In the methods for manufacturing a steel wire for a spring, the second drawing may be performed through a die with an approach angle of from 0.1° to 7°. This allows an increase in hardness to be easily achieved only in the surface layer.

[0038] In the methods for manufacturing a steel wire for a spring, the starting wire material may be drawn to a diameter of 15 mm or less by the first drawing. If the settings for the first drawing are made such that the starting wire material is drawn to a diameter of 15 mm or less, a thin steel wire for a spring can be easily manufactured.

[0039] A method for manufacturing a spring according to the present application includes the steps of providing a steel wire for a spring by the methods for manufacturing a steel wire for a spring according to the present application; and coiling the steel wire for a spring.

[0040] Since a steel wire for a spring manufactured by the methods for manufacturing a steel wire for a spring according to the present application is coiled in the method for manufacturing a spring according to the present application, a spring that exhibits improved fatigue strength can be manufactured with a reduced likelihood of fractures during coiling.

[0041] The method for manufacturing a spring may further include a step of subjecting the coiled steel wire for a spring to shot peening treatment. The steel wire for a spring to be subjected to the shot peening treatment may have a surface with a nitrogen concentration of 300 ppm or less. If the shot peening treatment is performed in the method for manufacturing a spring according to the present application without a treatment that increases the nitrogen concentration of the surface of the spring above such a range, for example, nitriding treatment, a spring that exhibits sufficient fatigue strength can be manufactured.

[Details of Embodiments of Invention]

[0042] Next, embodiments of methods for manufacturing steel wires according to the present invention will hereinafter be described with reference to the drawings. In the following drawings, the same or corresponding parts are denoted by the same reference numerals, and a description thereof is not repeated.

(First Embodiment)

[0043] Referring to Fig. 1, a steel wire 1 for a spring according to this embodiment is a steel wire having a circular cross-section 10 perpendicular to the longitudinal direction and a cylindrical outer surface 11. The steel wire 1 for a spring has a diameter of, for example, 15 mm or less, preferably from 2 mm to 10 mm.

[0044] The steel wire 1 for a spring is formed of a steel containing from 0.5% by mass to 0.8% by mass of carbon, from 1.0% by mass to 2.5% by mass of silicon, from 0.2% by mass to 1.0% by mass of manganese, and from 0.5% by mass to 2.5% by mass of chromium, the balance being iron and incidental impurities. The steel has a tempered martensite structure. The hardness of a surface region 12 that is a region within 10 μm from the outer surface 11 is from more than 0 HV to 50 HV higher than the hardness of an interior region 13 that is a region other than the surface region. The carbon concentration of the surface region 12 is from more than 0% by mass to 0.05% by mass higher than the carbon concentration of the interior region 13. The surface region 12 is a carburized layer.

[0045] The steel used for the steel wire 1 for a spring has the foregoing constituent composition, which can ensure the strength required of springs, and a tempered martensite structure. The hardness of an extremely thin surface region that is within 10 μm from the outer surface 11 (surface region 12) is set to be from more than 0 HV to 50 HV higher than the hardness of the interior region13. Since the hardness is increased only in the surface region 12 by 50 HV or less in this way, the steel wire 1 for a spring can achieve improved fatigue strength with a reduced likelihood of fractures during coiling. The hardness of the surface region 12 is preferably from 5 HV to 25 HV, preferably from 5 HV to 15 HV, higher than the hardness of the interior region 13. The carbon concentration of the surface region 12 is preferably from 0.01% by mass to 0.03% by mass, more preferably from 0.01% by mass to 0.02% by mass, higher than the carbon concentration of the interior region 13.

[0046] The proportion of the {110} texture in the surface region 12 of the steel wire 1 for a spring is preferably from 5% to 35% higher than the proportion of the {110} texture in a central region 14 that is a region within 10 μm from the center of gravity of a cross-section perpendicular to the longitudinal direction of the steel wire 1 for a spring. This increases the elastic limit for shear stress. As a result, the fatigue strength and settling resistance of a spring manufactured from the steel wire 1 for a spring can be improved. The proportion of the {110} texture in the central region 14 is, for example, 3% or less.

[0047] The steel wire 1 for a spring preferably has a circularity of 3 μm or less in the cross-section 10 perpendicular to the longitudinal direction. This stabilizes the properties of a spring manufactured from the steel wire 1 for a spring.

[0048] The steel wire 1 for a spring may have a variation in diameter of 1% or less per meter in the cross-section 10 perpendicular to the longitudinal direction. This stabilizes the properties of a spring manufactured from the steel wire 1 for a spring. The variation in diameter means the difference between the maximum and minimum diameters per meter in the longitudinal direction.

[0049] The steel forming the steel wire 1 for a spring may further contain from 0.05% by mass to 0.5% by mass of vanadium. This reduces softening upon heating.

[0050] Examples of steels that may be employed to form the steel wire 1 for a spring include SWOSC-B in accordance with JIS G3560 and SWOCV-V and SWOSC-V in accordance with JIS G3561.

[0051] Referring to Fig. 2, a spring 2 according to this embodiment is formed of the steel wire 1 for a spring. Since the spring 2 is formed of the steel wire 1 for a spring, the spring 2 exhibits improved fatigue strength with a reduced likelihood of fractures during coiling.

[0052] The surface of the spring 2 (the outer surface 11 of the steel wire 1 for a spring) has a nitrogen concentration of 300 ppm or less. The spring 2 exhibits sufficient fatigue strength without a treatment that increases the nitrogen concentration of the surface of the spring 2 (the outer surface 11 of the steel wire 1 for a spring) above such a range, for example, nitriding treatment.

[0053] Next, an example method for manufacturing the steel wire 1 for a spring and the spring 2 will be described. Referring to Fig. 3, a method for manufacturing the steel wire 1 for a spring according to this embodiment begins by performing a starting-wire-material providing step as step (S10). Referring to Fig. 4, a starting wire material 5 is provided in step (S10). The starting wire material 5 contains from 0.5% by mass to 0.8% by mass of carbon, from 1.0% by mass to 2.5% by mass of silicon, from 0.2% by mass to 1.0% by mass of manganese, and from 0.5% by mass to 2.5% by mass of chromium, the balance being iron and incidental impurities.

[0054] Specifically, for example, the starting wire material 5 is provided by subjecting a steel material such as

SWOSC-B in accordance with JIS G3560 or SWOCV-V or SWOSC-V in accordance with JIS G3561 to processes such as rolling and patenting (transformation into fine pearlite). The starting wire material 5 is a steel wire material having a circular cross-section 50 perpendicular to the longitudinal direction and a cylindrical outer surface 51.

[0055] A first drawing step is then performed as step (S20). In step (S20), the starting wire material 5 is subjected to first drawing (drawing process). Specifically, the starting wire material 5 provided in step (S10) is drawn. In step (S20), the starting wire material 5 is drawn to a diameter of, for example, 15 mm or less.

[0056] A carburizing step is then performed as step (S30). Figure 5 shows the relationship between time and temperature in the carburizing step and the quenching and tempering step. In Fig. 5, the horizontal axis indicates elapsed time, and the vertical axis indicates temperature. In step (S30), the starting wire material 5 subjected to the first drawing in step (S20) is subjected to carburizing treatment.

[0057] Specifically, referring to Fig. 5, the starting wire material 5 subjected to the first drawing in step (S20) begins to be heated at time t_0 and reaches a carburizing temperature T_1 at time t_1. Thereafter, the starting wire material 5 is maintained at the carburizing temperature T_1 until time t_2. The carburizing temperature T_1 is a temperature higher than or equal to the austenite transformation point (A_1 transformation point). For example, the carburizing temperature T_1 is from 920°C to 930°C. During this period, the starting wire material 5 is held in a carburizing atmosphere. That is, the starting wire material 5 is heated in a carburizing atmosphere. As a result, the carbon concentration of the region including the surface (outer surface 51) of the starting wire material 5 becomes slightly, specifically, from more than 0% by mass to 0.05% by mass, higher than the carbon concentration of the interior thereof.

[0058] In step (S30), the composition of the atmosphere is controlled such that the CP value of the atmosphere is from 0.5% by mass to 1.5% by mass, more preferably from 0.8% by mass to 1.2% by mass. More specifically, gases such as propane gas, oxygen gas, and nitrogen gas are introduced into a furnace in which the carburizing treatment is performed. The introduced propane gas decomposes and reacts with the oxygen gas to produce gases such as carbon monoxide gas (CO) and methane gas (CH_4), which contribute to carburizing, as well as carbon dioxide gas (CO_2). The CP value can be controlled, for example, by measuring the concentrations of carbon dioxide gas and oxygen gas in the atmosphere with a carbon dioxide sensor and an oxygen sensor and, based on these measurements, changing the amounts of propane gas and oxygen gas introduced into the furnace.

[0059] If the carburizing treatment is performed in this way by gas carburizing while measuring the gas composition of the atmosphere and controlling the CP value based on these measurements, the carbon concentration of the surface region 12 becomes stable. As a result, the variation in the hardness of the surface region 12 is reduced, and the steel wire 1 for a spring can be easily manufactured such that the hardness of the surface region 12 is from more than 0 HV to 50 HV higher than the hardness of the interior region 13.

[0060] A quenching and tempering step is then performed as step (S40). In step (S40), the starting wire material 5 subjected to the carburizing treatment in step (S30) is subjected to quenching and tempering treatment. Referring to Fig. 5, the starting wire material 5 subjected to the carburizing treatment over the period from time t_1 to t_2 is quenched over the period from time t_2 to t_3. Specifically, the starting wire material 5 is cooled from a temperature higher than or equal to the austenite transformation point (A_1 transformation point) to a temperature lower than or equal to the M_s point. Cooling can be performed, for example, by immersing the starting wire material 5 in quenching oil. This transforms the structure of the steel forming the starting wire material 5 into a martensite structure. Thus, the quenching treatment is complete.

[0061] The starting wire material 5 then begins to be heated at time t_4 and reaches a tempering temperature T_2 at time t_5. Thereafter, the starting wire material 5 is maintained at the tempering temperature T_2 until time t_6. The tempering temperature T_2 is a temperature lower than the austenite transformation point (A_1 transformation point). For example, the tempering temperature T_2 is from 450°C to 600°C. The starting wire material 5 is then cooled over the period from time t_6 to t_7. Cooling can be performed, for example, by air cooling. This transforms the structure of the steel forming the starting wire material 5 into a tempered martensite structure. Thus, the tempering treatment is complete.

[0062] A second drawing step is then performed as step (S50). In step (S50), the starting wire material 5 subjected to the quenching and tempering treatment in step (S40) is subjected to second drawing.

[0063] Figure 6 shows a cross-section of a drawing device for performing step (S50) in the advancing direction α, of the starting wire material 5. Referring to Fig. 6, the drawing device for performing step (S50) includes a die 70. The die 70 has a through-hole formed through the die 70 in the advancing direction α of the starting wire material 5. The wall surface surrounding the through-hole is a working surface 71 that comes into contact with the starting wire material 5. The starting wire material 5 subjected to step (S40) advances in the longitudinal direction to enter the through-hole of the die 70. When the starting wire material 5 reaches an entrance 78, the outer surface 51 of the starting wire material 5 comes into contact with the working surface 71 of the die 70. The starting wire material 5 is then worked and plastically deformed such that the shape of the starting wire material 5 in a cross-section perpendicular to the longitudinal direction corresponds to the shape of the working surface 71 in a cross-section perpendicular to the advancing direction α of the starting wire material 5. The area of the through-hole of the die 70 in a cross-section perpendicular to the advancing direction α of the starting wire material 5 is smaller at an exit 79 than at the entrance 78. When the starting wire material 5 reaches the exit 79 of the die 70, working on the working surface 71 of the die 70 is complete, and the steel wire 1 for a spring is obtained.

[0064] The through-hole of the die 70 has a tapered region whose cross-sectional area perpendicular to the advancing direction α of the starting wire material 5 becomes smaller in the direction from the entrance 78 toward the exit 79. The taper angle of the tapered region, i.e., the approach angle θ, is from 0.1° to 7°.

[0065] In the method for manufacturing the steel wire 1 for a spring according to this embodiment, the starting wire material 5 having the foregoing suitable constituent composition is subjected to carburizing treatment in step (S30) to slightly increase the carbon concentration of the region including the surface, followed by quenching and tempering treatment in step (S40). This allows the hardness of the steel wire 1 for a spring, which is formed of a steel having a suitable constituent composition and a tempered martensite structure, to be slightly increased only in an extremely thin surface region as compared to the interior. As a result, the steel wire 1 for a spring can be easily manufactured such that the hardness of an extremely thin surface region that is within 10 μm from the outer surface 11 (surface region 12) is set to be from more than 0 HV to 50 HV higher than the hardness of the interior region 13.

[0066] Although step (S50) is not an essential step in the method for manufacturing a steel wire for a spring according to this embodiment, performing this step improves the dimensional accuracy of the steel wire 1 for a spring. The reduction of area in step (S50) is preferably from 1% to less than 5%, more preferably from 2% to 3.5%. This allows an increase in hardness to be achieved only in the surface layer, so that the steel wire 1 for a spring can be more easily manufactured. Performing step (S50) also increases the proportion of the {110} texture in the surface region 12 while maintaining the proportion of the {110} texture in the central region 14 at a low level (e.g., 3% or less). As a result, the proportion of the {110} texture in the surface region 12 can be made, for example, from 5% to 35% higher than the proportion of the {110} texture in the central region 14.

[0067] The second drawing in step (S50) may be performed while the starting wire material 5 is heated to a temperature range from 150°C to 450°C, preferably from 200°C to 350°C. That is, the starting wire material 5 may be subjected to warm working (warm drawing) in step (S50). This forms a Cottrell atmosphere in the steel, thus increasing the strength of the steel wire 1 for a spring. The second drawing in step (S50) may be performed while the starting wire material 5 is heated to a temperature range from 25°C to 450°C.

[0068] Next, a method for manufacturing the spring 2 from the steel wire 1 for a spring obtained in step (S50) will be described. Following step (S50), a coiling step is performed as step (S60). Referring to Figs. 1 and 2, the steel wire 1 for a spring is coiled in step (S60), for example, by plastically forming the steel wire 1 for a spring into the spiral shape shown in Fig. 2.

[0069] An tempering step is then performed as step (S70). In step (S70), the steel wire 1 for a spring coiled in step (S60) (spring 2) is subjected to tempering treatment. Specifically, the spring 2 is heated to reduce strain induced into the spring 2 in step (S60).

[0070] A shot peening step is then performed as step (S80). In step (S80), the spring 2 subjected to the tempering treatment in step (S70) is subjected to shot peening. Although step (S80) is not an essential step in the method for manufacturing a spring according to this embodiment, performing this step applies a compressive stress to the region including the surface of the spring 2, thus contributing to improved fatigue strength. The spring 2 according to this embodiment is finished through the foregoing steps. The method for manufacturing a spring according to this embodiment allows a spring that exhibits improved fatigue strength to be manufactured with a reduced likelihood of fractures during coiling.

[0071] The steel wire 1 for a spring (spring 2) to be subjected to the shot peening in step (S80) may have a surface with a nitrogen concentration of 300 ppm or less. That is, the shot peening in step (S80) may be performed without subjecting the spring 2 to nitriding treatment. If the shot peening treatment is performed without nitriding treatment in the method for manufacturing the spring 2 according to this embodiment, a spring with sufficient fatigue strength can be manufactured.

(Second Embodiment)

[0072] Next, another embodiment, i.e., a second embodiment, will be described. A steel wire 1 for a spring and a spring 2 according to the second embodiment basically have the same configuration and advantages as those according to the first embodiment. However, the steel wire 1 for a spring and the spring 2 according to the second embodiment differ from those according to the first embodiment in that they have no carburized layer.

[0073] Referring to Figs. 1 and 2, as in the first embodiment, the hardness of the surface region 12 of the steel wire 1 for a spring and the spring 2 according to the second embodiment is higher than the hardness of the interior region 13; however, they have the same carbon concentration. That is, the carbon concentration is uniform in the cross-section 10 perpendicular to the longitudinal direction. Even with this configuration, the steel wire 1 for a spring and the spring 2 can achieve improved fatigue strength with a reduced likelihood of fractures during coiling.

[0074] Next, a method for manufacturing a steel wire for a spring and a spring according to the second embodiment will be described. Referring to Figs. 7 and 3, the method for manufacturing a steel wire for a spring and a spring according to the second embodiment is basically performed as in the first embodiment. However, the method for manufacturing a steel wire for a spring and a spring according to the second embodiment differs from that according to the first embodiment in that the carburizing treatment performed as step (S30) is omitted and the second drawing step performed as step (S50) is an essential step.

[0075] Referring to Fig. 7, the method for manufacturing a steel wire for a spring and a spring according to the second embodiment begins by performing steps (S10) and (S20) as in the first embodiment. Thereafter, steps (S40) and (S50) are performed without performing step (S30). Whereas step (S50) is not an essential step in the first embodiment, step (S50) is an essential step in the second embodiment.

[0076] The reduction of area in step (S50) is from 1% to less than 5%, preferably from 2% to 3.5%. This allows an increase in hardness to be achieved only in the surface layer even through the carburizing step performed as step (S30) in the first embodiment is omitted, so that the steel wire 1 for a spring according to the second embodiment can be manufactured. Furthermore, the spring 2 according to the second embodiment can be manufactured by performing steps (S60) to (S80) as in the first embodiment.

[0077] It should be understood that the embodiments disclosed herein are illustrative in all respects and not restrictive in any way. The scope of the invention is defined by the claims, rather than by the foregoing description, and all changes that come within the meaning and range of equivalency of the claims are intended to be embraced therein.

Reference Signs List

[0078] 1 steel wire for spring; 2 spring; 5 starting wire material; 10 cross-section; 11 outer surface; 12 surface region; 13 interior region; 14 central region; 50 cross-section; 51 outer surface; 70 die; 71 working surface; 78 entrance; 79 exit

Claims

1. A steel wire for a spring, comprising a steel containing from 0.5% by mass to 0.8% by mass of carbon, from 1.0% by mass to 2.5% by mass of silicon, from 0.2% by mass to 1.0% by mass of manganese, and from 0.5% by mass to 2.5% by mass of chromium, the balance being iron and incidental impurities, the steel having a tempered martensite structure,
   wherein a hardness of a surface region that is a region within 10 μm from an outer surface is from more than 0 HV to 50 HV higher than a hardness of a region other than the surface region.

2. The steel wire for a spring according to Claim 1, wherein the steel wire for a spring has a diameter of 15 mm or less.

3. The steel wire for a spring according to Claim 1 or 2, wherein a carbon concentration of the surface region is from more than 0% by mass to 0.05% by mass higher than a carbon concentration of the region other than the surface region.

4. The steel wire for a spring according to any one of Claims 1 to 3, wherein a proportion of a {110} texture in the surface region is from 5% to 35% higher than a proportion of a {110} texture in a central region that is a region within 10 μm from a center of gravity of a cross-section perpendicular to a longitudinal direction of the steel wire for a spring.

5. The steel wire for a spring according to any one of Claims 1 to 4, wherein the steel wire for a spring has a circularity of 3 μm or less in a cross-section perpendicular to a longitudinal direction.

6. The steel wire for a spring according to any one of Claims 1 to 5, wherein the steel wire for a spring has a variation in diameter of 1% or less per meter in a cross-section perpendicular to a longitudinal direction.

7. The steel wire for a spring according to any one of Claims 1 to 6, wherein the steel further contains from 0.05% by mass to 0.5% by mass of vanadium.

8. A spring comprising the steel wire for a spring according to any one of Claims 1 to 7.

9. The spring according to Claim 8, wherein the spring has a surface with a nitrogen concentration of 300 ppm or less.

10. A method for manufacturing a steel wire for a spring, comprising the steps of:

    providing a starting wire material containing from 0.5% by mass to 0.8% by mass of carbon, from 1.0% by mass to 2.5% by mass of silicon, from 0.2% by mass to 1.0% by mass of manganese, and from 0.5% by mass to 2.5% by mass of chromium, the balance being iron and incidental impurities;
    subjecting the starting wire material to first drawing;
    subjecting to carburizing treatment the starting wire material subjected to the first drawing such that a carbon concentration of a region including a surface of the starting wire material is from more than 0% by mass to 0.05% by mass higher than a carbon concentration of an interior there-

of; and
subjecting to quenching and tempering treatment the starting wire material subjected to the carburizing treatment.

11. The method for manufacturing a steel wire for a spring according to Claim 10, wherein the step of subjecting to carburizing treatment the starting wire material subjected to the first drawing comprises performing carburizing treatment by heating the starting wire material in an atmosphere whose composition is controlled to have a CP value of from 0.5% by mass to 1.5% by mass.

12. The method for manufacturing a steel wire for a spring according to Claim 10 or 11, further comprising a step of subjecting to second drawing the starting wire material subjected to the quenching and tempering treatment.

13. The method for manufacturing a steel wire for a spring according to Claim 12, wherein the second drawing is performed at a reduction of area of from 1% to less than 5%.

14. A method for manufacturing a steel wire for a spring, comprising the steps of:

providing a starting wire material containing from 0.5% by mass to 0.8% by mass of carbon, from 1.0% by mass to 2.5% by mass of silicon, from 0.2% by mass to 1.0% by mass of manganese, and from 0.5% by mass to 2.5% by mass of chromium, the balance being iron and incidental impurities;
subjecting the starting wire material to first drawing;
subjecting to quenching and tempering treatment the starting wire material subjected to the first drawing; and
subjecting to second drawing the starting wire material subjected to the quenching and tempering treatment,
wherein the second drawing is performed at a reduction of area of from 1% to less than 5%.

15. The method for manufacturing a steel wire for a spring according to any one of Claims 12 to 14, wherein the second drawing is performed while the starting wire material is heated to a temperature range from 25°C to 450°C.

16. The method for manufacturing a steel wire for a spring according to any one of Claims 12 to 15, wherein the second drawing is performed through a die with an approach angle of from 0.1° to 7°.

17. The method for manufacturing a steel wire for a spring according to any one of Claims 10 to 16, wherein the starting wire material is drawn to a diameter of 15 mm or less by the first drawing.

18. A method for manufacturing a spring, comprising the steps of:

providing a steel wire for a spring by the method for manufacturing a steel wire for a spring according to any one of Claims 10 to 17; and
coiling the steel wire for a spring.

19. The method for manufacturing a spring according to Claim 18, further comprising a step of subjecting the coiled steel wire for a spring to shot peening treatment,
wherein the steel wire for a spring to be subjected to the shot peening treatment has a surface with a nitrogen concentration of 300 ppm or less.

FIG. 1

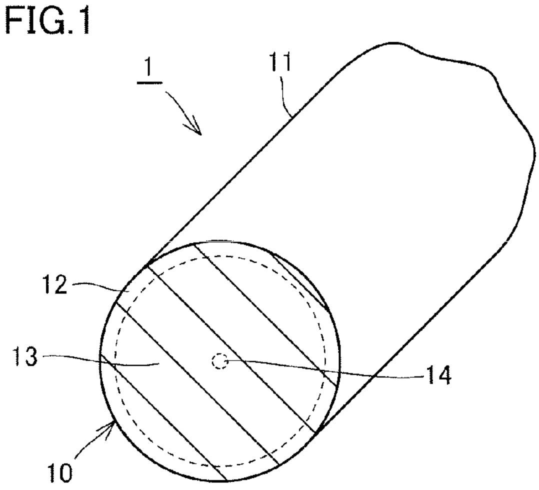

FIG. 2

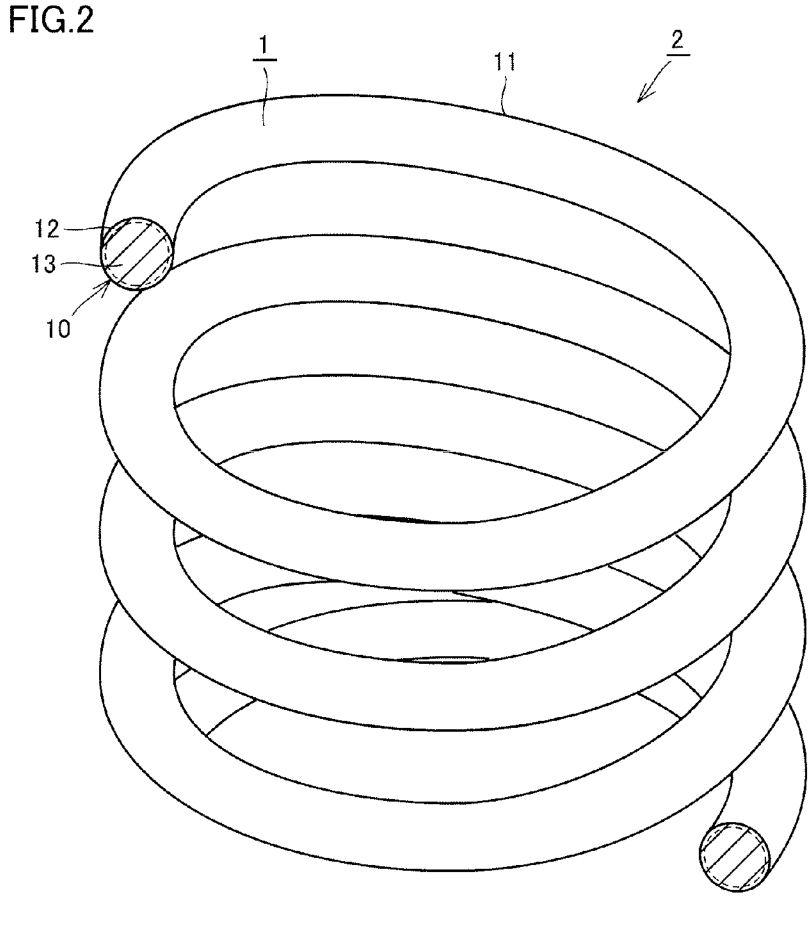

FIG. 3

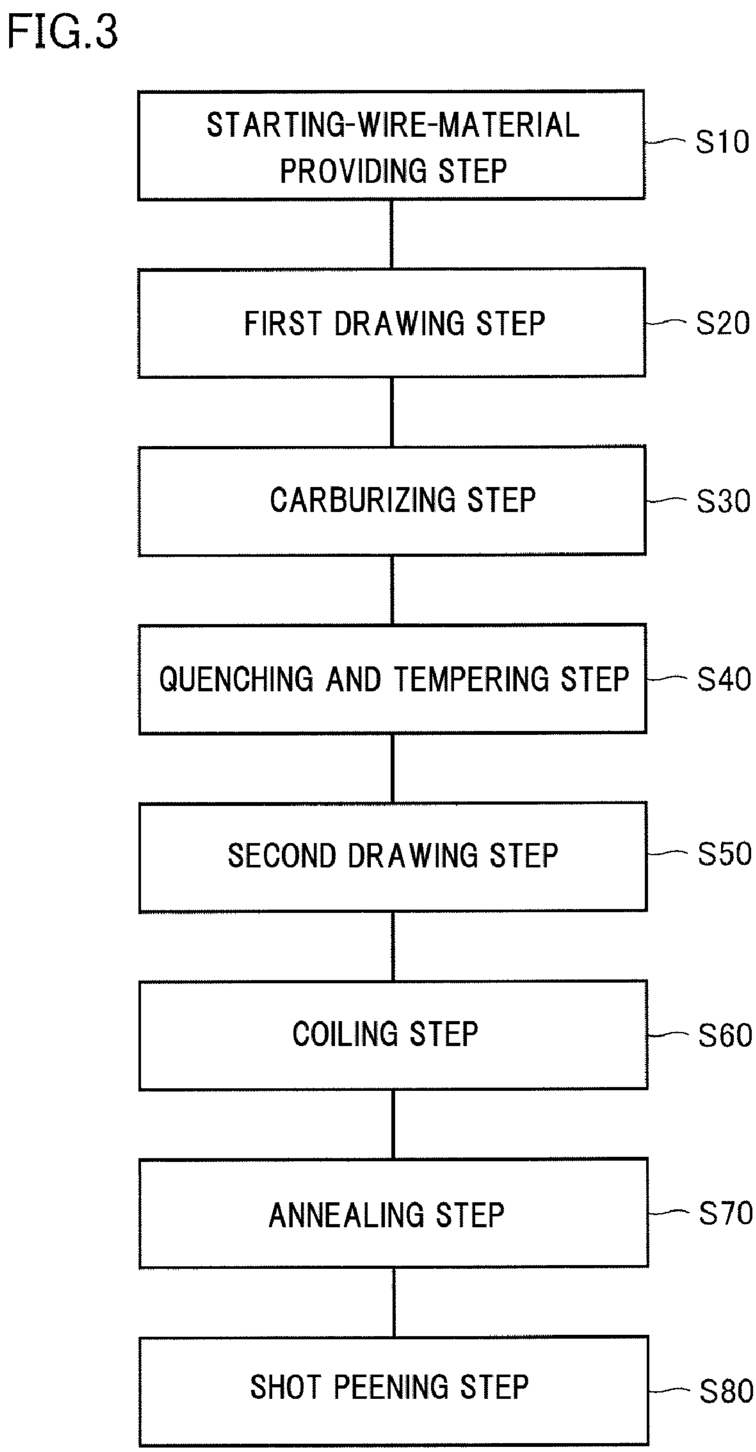
FIG.3
STARTING-WIRE-MATERIAL PROVIDING STEP
S10
FIRST DRAWING STEP
S20
CARBURIZING STEP
S30
QUENCHING AND TEMPERING STEP
S40
SECOND DRAWING STEP
S50
COILING STEP
S60
ANNEALING STEP
S70
SHOT PEENING STEP
S80

FIG. 4

FIG.4

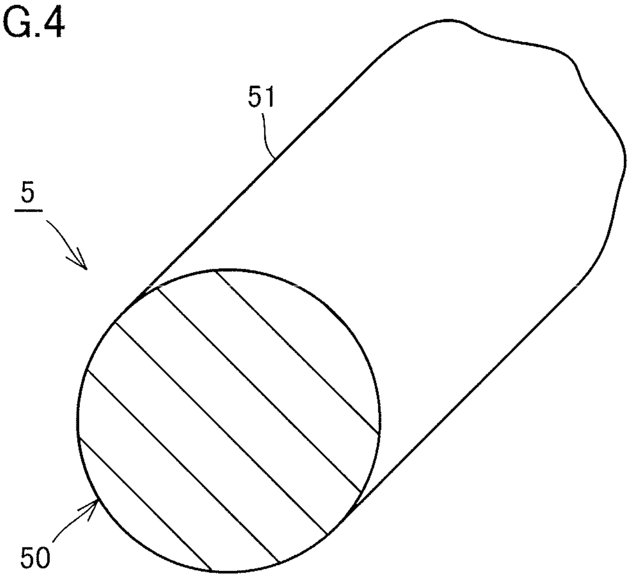

FIG. 5

FIG.5

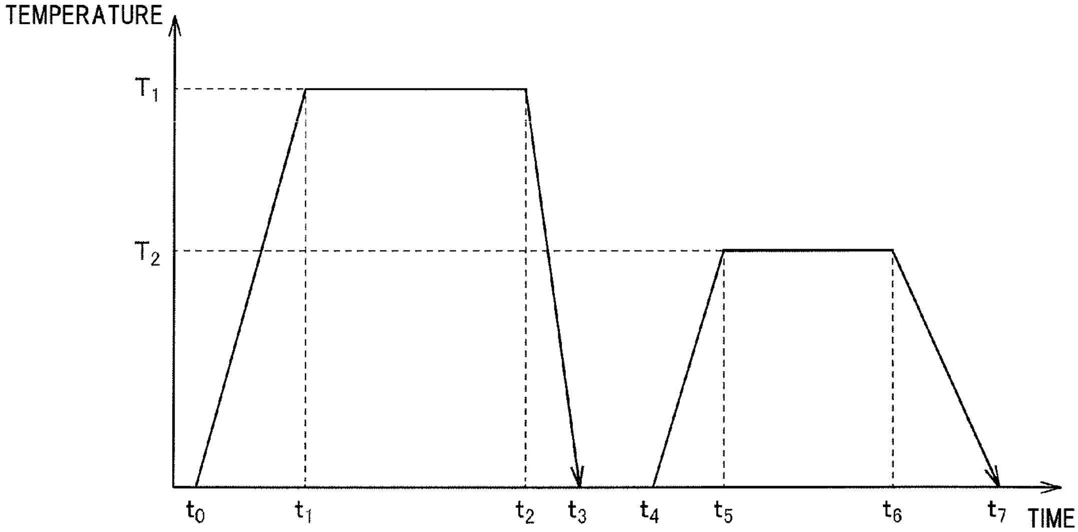

FIG. 6

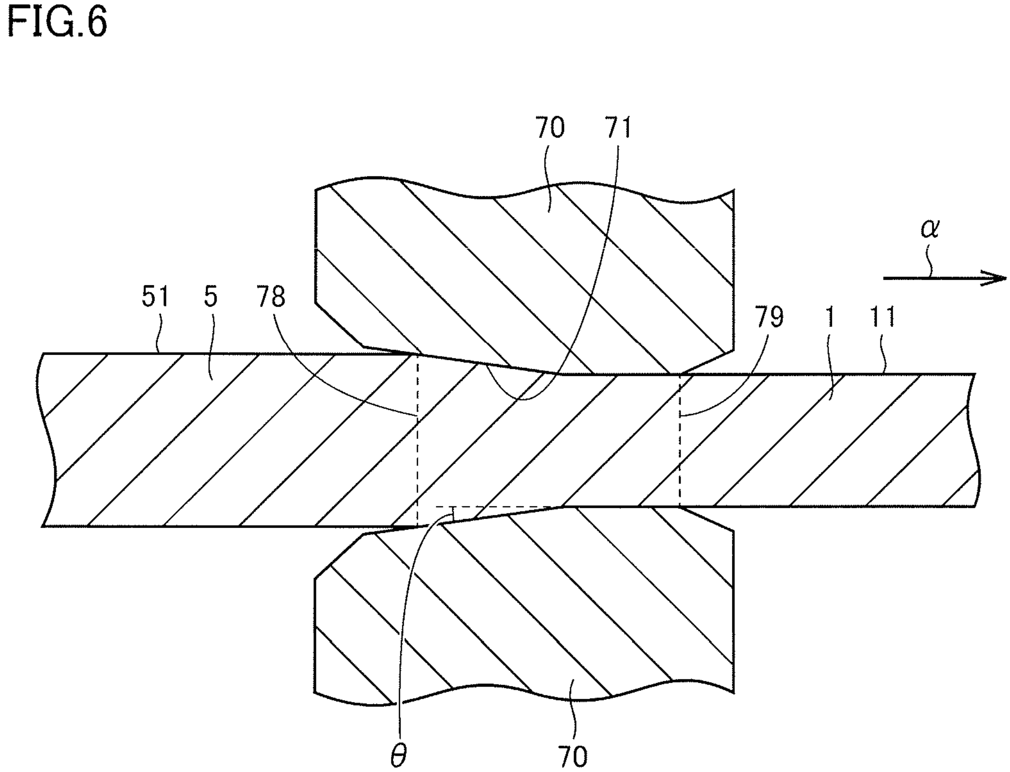

FIG. 7

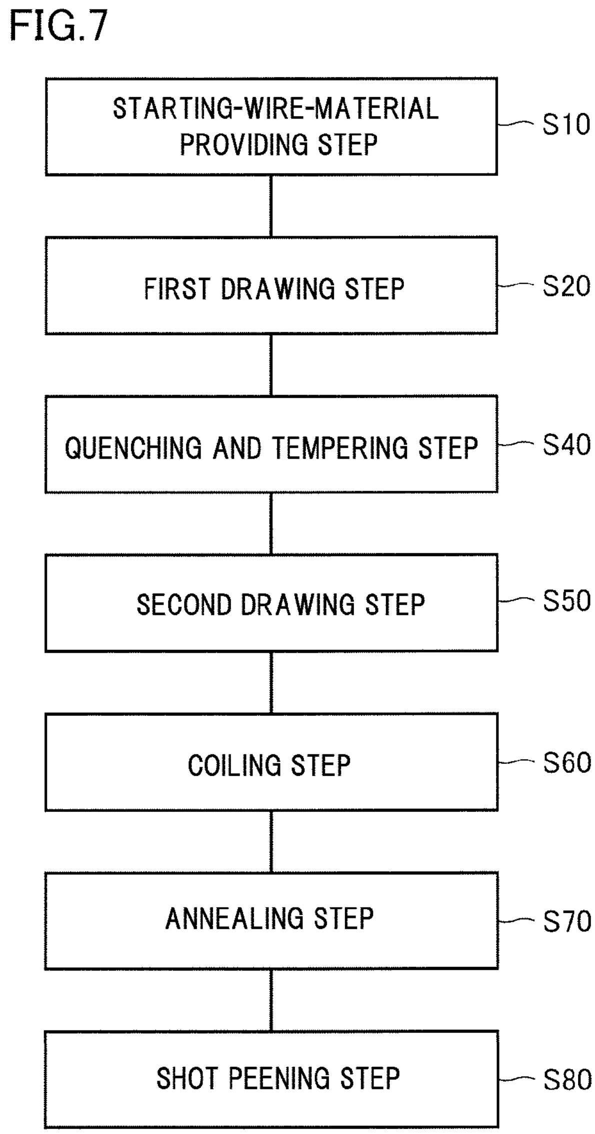
FIG.7
STARTING-WIRE-MATERIAL PROVIDING STEP
S10
FIRST DRAWING STEP
S20
QUENCHING AND TEMPERING STEP
S40
SECOND DRAWING STEP
S50
COILING STEP
S60
ANNEALING STEP
S70
SHOT PEENING STEP
S80

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/021367

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *B21C3/02*(2006.01)i, *C21D1/06*(2006.01)i, *C21D7/06*(2006.01)i, *C21D8/06*(2006.01)i, *C21D9/02*(2006.01)i, *C22C38/34*(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00, B21C3/02, C21D1/06, C21D7/06, C21D8/06, C21D9/02, C22C38/34

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.
X A	JP 2014-206219 A (NHK Spring Co., Ltd.), 30 October 2014 (30.10.2014), paragraphs [0018] to [0028], [0032] to [0035], [0040] to [0049]; tables 1 to 3; invention example 11 (Family: none)	1-2,7-9 3-6,10-19
X A	JP 2014-55343 A (NHK Spring Co., Ltd.), 27 March 2014 (27.03.2014), paragraphs [0021] to [0028], [0058]; tables 1 to 3; comparative example 2 & US 2015/0252863 A1 paragraphs [0020] to [0028], [0063]; tables 1 to 3; comparative example 2 & WO 2014/042066 A1 & EP 2896712 A1 & CN 104619878 A & KR 10-2015-0054969 A	1-2,8-9 3-7,10-19

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

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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

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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
30 August 2017 (30.08.17)	12 September 2017 (12.09.17)

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

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

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2017/021367

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 2012-52218 A (Sumitomo Electric Industries, Ltd.), 15 March 2012 (15.03.2012), (Family: none)	1-19
A	JP 2014-227581 A (Sumitomo Electric Industries, Ltd.), 08 December 2014 (08.12.2014), (Family: none)	1-19

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

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2016139668 A **[0002]**
- JP 2017038665 A **[0002]**
- JP 2012052218 A **[0003] [0004]**