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(54) **WIRE ROD FOR ULTRA-HIGH STRENGTH SPRING, STEEL WIRE AND MANUFACTURING METHOD THEREOF**

(57) Disclosed are a wire rod for an ultra-high strength spring, a steel wire, and a manufacturing method thereof, and more particularly, a wire rod for an ultra-high strength spring having excellent processibility, a steel wire, and a manufacturing method thereof.

According to an embodiment, the disclosed wire rod for an ultra-high strength spring includes, in percent by weight (wt%), 0.55 to 0.65% of C, 0.5 to 0.9% of Si, 0.3 to 0.8% of Mn, 0.3 to 0.6% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.005% or less of N, more than 0% and 0.04% or less of Nb, and the remainder being Fe and unavoidable impurities, and satisfies a value of Formula (1) below being 0.77 or more and 0.83 or less:

$$(1)\ C + 1/6{*}Mn + 1/5{*}Cr + 1/24{*}Si \qquad (1)$$

wherein in Formula (1), C, Mn, Cr, and Si represent the content (wt%) of each element.

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Description

[Technical Field]

[0001] The present disclosure relates to a wire rod for an ultra-high strength spring, a steel wire and a manufacturing method thereof, and more particularly, to a wire rod for an ultra-high strength spring having excellent processibility, a steel wire and a manufacturing method thereof.

[Background Art]

[0002] Similar to the market for automotive materials, development of lightweight materials or structural modification has been continuously conducted in the market for motorcycle materials. Demands for steels for high-strength springs have recently increased since dual-type suspensions used in conventional motorcycles have been replaced with mono-type suspensions.

[0003] Drawn wire rods, which have been conventionally used for springs of motorcycle suspensions, are not suitable for use in mono-type suspensions due to insufficient strength and fatigue resistance. Accordingly, application of wire rods having a tempered martensite structure for automobiles has been considered. However, because quality standards for suspension springs of automobiles are stringent and also manufacturing the suspension springs is difficult and costly, it is difficult to apply the suspension springs for automobiles to motorcycles.

[0004] Particularly, suspensions of motorcycles are smaller than those of automobiles, springs for motorcycles require relatively higher processibility while processing the springs. In addition, suspension springs for motorcycles have relatively smaller diameters, it is difficult to control decarburization and a low-temperature structure. Therefore, there is a need to develop new high-strength suspension springs applicable to suspensions of motorcycles.

[0005] In addition, conventionally, oil quenching has been used after heating a steel material in a heat treatment furnace to form a tampered martensite structure and manganese and chromium should be contained in the steel material in more than certain amounts to obtain sufficient hardenability. With the recent development of induction heat treatment, sufficient hardenability may be obtained only by water quenching and a target strength may be obtained while reducing the amounts of the alloying elements contained in the steel material. However, research on small-diameter steel materials applicable to suspension springs of motorcycles and having lower amounts of the alloying elements by utilizing induction heat treatment and quenching is not sufficient.

[Disclosure]

[Technical Problem]

[0006] To solve the above-described problems, provided is a wire rod for an ultra-high strength spring having excellent processibility, a steel wire and a manufacturing method thereof.

[Technical Solution]

[0007] In accordance with an aspect of the present disclosure to achieve the above-described objects, provided is a wire rod for an ultra-high strength spring including, in percent by weight (wt%), 0.55 to 0.65% of C, 0.5 to 0.9% of Si, 0.3 to 0.8% of Mn, 0.3 to 0.6% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.005% or less of N, more than 0% and 0.04% or less of Nb, and the remainder being Fe and unavoidable impurities, and satisfying a value of Formula (1) below being 0.77 or more and 0.83 or less:

$$(1)\ C + 1/6*Mn + 1/5*Cr + 1/24*Si$$

wherein in Formula (1), C, Mn, Cr, and Si represent the content (wt%) of each element.

[0008] In the wire rod for an ultra-high strength spring according to an embodiment of the present disclosure, on a cross-section perpendicular to a longitudinal direction, a sum of area fractions of bainite and martensite having a hardness may be 400 Hv or more is 1% or less.

[0009] In the wire rod for an ultra-high strength spring according to an embodiment of the present disclosure, a ferrite decarburized layer may have a thickness of 1 μm or less.

[0010] In the wire rod for an ultra-high strength spring according to an embodiment of the present disclosure, an average grain size of ferrite may be 10 μm or less.

[0011] In the wire rod for an ultra-high strength spring according to an embodiment of the present disclosure, an Nb-based carbide having a size of 20 nm or less may be distributed at a density of 1000 grains/mm^2 or more.

[0012] In the wire rod for an ultra-high strength spring according to an embodiment of the present disclosure, a tensile strength may be 1200 MPa or less.

[0013] In accordance with another aspect of the present disclosure to achieve the above-described objects, provided is a method for manufacturing a wire rod for an ultra-high strength spring including: homogenization heat-treating an ingot including, in percent by weight (wt%), 0.55 to 0.65% of C, 0.5 to 0.9% of Si, 0.3 to 0.8% of Mn, 0.3 to 0.6% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.005% or less of N, more than 0% and 0.04% or less of Nb, and the remainder being Fe and unavoidable impurities, and satisfying a value of Formula (1) below being 0.77 or more and 0.83 or less, at a heating temperature of 900 to 1100°C within 180 minutes; wire rod rolling the ingot at a finish rolling temperature of 730 to Ae3°C; and cooling the wire rod at a cooling rate of 3°C/s or less:

$$(1)\ C + 1/6{*}Mn + 1/5{*}Cr + 1/24{*}Si$$

wherein in Formula (1), C, Mn, Cr, and Si represent the content (wt%) of each element.

[0014] In the method for manufacturing a wire rod for an ultra-high strength spring according to an embodiment of the present disclosure, a strain in the wire rod rolling may be from 0.3 to 2.0.

[0015] In the method for manufacturing a wire rod for an ultra-high strength spring according to an embodiment of the present disclosure, an average grain size of austenite before finish rolling in the wire rod rolling may be from 5 to 15 μm.

[0016] In accordance with another aspect of the present disclosure to achieve the above-described objects, provided is a steel wire for an ultra-high strength spring including, in percent by weight (wt%), 0.55 to 0.65% of C, 0.5 to 0.9% of Si, 0.3 to 0.8% of Mn, 0.3 to 0.6% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.005% or less of N, more than 0% and 0.04% or less of Nb, and the remainder being Fe and unavoidable impurities, and satisfying a value of Formula (1) below being 0.77 or more and 0.83 or less, wherein the steel wire includes a tempered martensite in an area fraction of 90% or more:

$$(1)\ 0.77 \le C + 1/6{*}Mn + 1/5{*}Cr + 1/24{*}Si \le 0.83$$

wherein in Formula (1), C, Mn, Cr, and Si represent the content (wt%) of each element.

[0017] In the steel wire for an ultra-high strength spring according to an embodiment of the present disclosure, an Nb-based carbide having a size of 20 nm or less may be distributed at a density of 1000 grains/mm^2 or more.

[0018] In the steel wire for an ultra-high strength spring according to an embodiment of the present disclosure, an average grain size of spherical austenite may be 10 μm or less.

[0019] In the steel wire for an ultra-high strength spring according to an embodiment of the present disclosure, a wire diameter may be 15 mm or less.

[0020] In the steel wire for an ultra-high strength spring according to an embodiment of the present disclosure, a strength may be 1700 MPa or more.

[0021] In the steel wire for an ultra-high strength spring according to an embodiment of the present disclosure, a reduction in area may be 35% or more.

[0022] In accordance with another aspect of the present disclosure to achieve the above-described objects, provided is a method for manufacturing a steel wire for an ultra-high strength spring including: drawing a wire rode including, in percent by weight (wt%), 0.55 to 0.65% of C, 0.5 to 0.9% of Si, 0.3 to 0.8% of Mn, 0.3 to 0.6% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.005% or less of N, more than 0% and 0.04% or less of Nb, and the remainder being Fe and unavoidable impurities, and satisfying a value of Formula (1) below being 0.77 or more and 0.83 or less, heating the wire rod at a temperature of 900 to 1000°C, water quenching the wire rod at a high pressure, tempering the wire rod at a temperature of 400 to 500°C, and water quenching the wire rod:

$$(1)\ C + 1/6{*}Mn + 1/5{*}Cr + 1/24{*}Si$$

wherein in Formula (1), C, Mn, Cr, and Si represent the content (wt%) of each element.

[0023] In the method for manufacturing a steel wire for an ultra-high strength spring according to an embodiment of the present disclosure, the heating step may include heating the wire rod to a temperature of 900 to 1000°C within 10 seconds and maintaining the temperature for 5 to 60 seconds.

[0024] In the method for manufacturing a steel wire for an ultra-high strength spring according to an embodiment of the present disclosure, wherein an average grain size of spherical austenite after the heating step may be 10 μm or less.

[0025] In the method for manufacturing a steel wire for an ultra-high strength spring according to an embodiment of the present disclosure, the tempering step may include heating the wire rod to a temperature of 400 to 500°C within 10 seconds and maintaining the temperature within 30 seconds.

[Advantageous Effects]

[0026] According to the present disclosure, a wire rod for an ultra-high strength spring, in which surface decarburization and formation of a low-temperature structure are inhibited by using an alloy composition having a low C_{eq} and a low Si content, may be provided.

[0027] In addition, according to the present disclosure, a wire rod for an ultra-high strength spring, in which grain size is reduced by using an Nb-based carbide and controlling rolling may be provided.

[0028] A steel wire for an ultra-high strength spring according to the present disclosure has a small wire diameter of 15 mm or less which is suitable for suspension springs for motorcycles.

[0029] The steel wire for an ultra-high strength spring according to the present disclosure may have a strength of 1700 MPa or more by induction heat treatment and water quenching, although the alloy composition has a low C_{eq} and a low Si content, thereby having an ultra-high strength required for suspension springs of motorcycles.

[0030] The steel wire for an ultra-high strength spring according to the present disclosure may have a high ductility with a reduction in area (RA) of 35% or more by grain refinement, and thus the steel wire may be cold-rolled at room temperature to be manufactured into suspension springs for motorcycles.

[Best Mode]

[0031] A wire rod for an ultra-high strength spring according to an embodiment of the present disclosure includes, in percent by weight (wt%), 0.55 to 0.65% of C, 0.5 to 0.9% of Si, 0.3 to 0.8% of Mn, 0.3 to 0.6% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.005% or less of N, more than 0% and 0.04% or less of Nb, and the remainder being Fe and unavoidable impurities, wherein a value of Formula (1) below is 0.77 or more and 0.83 or less:

$$(1)\ C + 1/6*Mn + 1/5*Cr + 1/24*Si$$

wherein in Formula (1), C, Mn, Cr, and Si represent the content (wt%) of each element.

[Modes of the Invention]

[0032] Hereinafter, preferred embodiments of the present disclosure will now be described. However, the present disclosure may be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the disclosure to those skilled in the art.

[0033] The terms used herein are merely used to describe particular embodiments. Thus, an expression used in the singular encompasses the expression of the plural, unless it has a clearly different meaning in the context. In addition, it is to be understood that the terms such as "including" or "having" are intended to indicate the existence of features, steps, functions, components, or combinations thereof disclosed in the specification, and are not intended to preclude the possibility that one or more other features, steps, functions, components, or combinations thereof may exist or may be added.

[0034] Meanwhile, unless otherwise defined, all terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. Thus, these terms should not be interpreted in an idealized or overly formal sense unless expressly so defined herein. As used herein, the singular forms are intended to include the plural forms as well, unless the context clearly indicates otherwise.

[0035] In addition, the terms "about", "substantially", etc. used throughout the specification mean that when a natural manufacturing and substance allowable error are suggested, such an allowable error corresponds a value or is similar to the value, and such values are intended for the sake of clear understanding of the present invention or to prevent an unconscious infringer from illegally using the disclosure of the present invention.

[0036] The present inventors have found an optimal alloy composition having a low C_{eq} and a low Si content and efficient for inhibiting surface decarburization and formation of a low-temperature structure to provide a wire rod and a steel wire for an ultra-high strength spring having excellent processibility. An ultra-high strength spring may be manufactured by cold forming the steel wire disclosed in this specification at room temperature and the steel wire may be manufactured by drawing the wire rod disclosed in this specification.

[0037] The wire rod for an ultra-high strength spring according to an embodiment of the present disclosure may include, in percent by weight (wt%), 0.55 to 0.65% of C, 0.5 to 0.9% of Si, 0.3 to 0.8% of Mn, 0.3 to 0.6% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.005% or less of N, more than 0% and 0.04% or less of Nb, and the remainder being Fe and unavoidable impurities.

[0038] Hereinafter, reasons for numerical limitations on the contents of elements of the alloy composition will be described in detail.

Carbon (C): 0.55 to 0.65 wt%

[0039] C is an element added to obtain strength of products. When the C content is less than 0.55%, a target strength and a low carbon equivalent (Ceq) cannot be obtained. Accordingly, a martensite structure is not completely formed during cooling, and thus it difficult to obtain strength. Even when the martensite structure is formed, it may be difficult to obtain the target strength. When the C content exceeds 0.65%, impact resistance may deteriorate and quenching cracks may occur during water quenching. Therefore, the C content may be controlled from 0.55 to 0.65 wt%.

Silicon (Si): 0.5 to 0.9 wt%

[0040] Si is used for deoxidization of steels and is also effective for enhancing strength via solid solution strengthening. Si may be added in an amount of 0.5 wt% or more to obtain strength in the present disclosure. However, an excess of Si may cause surface decarbonization and make it difficult to process materials, and thus an upper limit thereof may be controlled to 0.9 wt% in consideration thereof. As described above, according to the present disclosure, surface decarburization is inhibited and sufficient processibility is obtained using a low Si alloy designed to control the Si content to 0.9 wt% or less.

Manganese (Mn): 0.3 to 0.8 wt%

[0041] Manganese enhances hardenability as an essential element for forming a steel having a high-strength tempered martensite structure. To obtain strength, manganese may be added in an amount of 0.3 wt% or more in the present disclosure. However, when the Mn content is excessive in a steel having a tempered martensite structure, toughness decreases, and therefore an upper limit of the Mn content may be controlled to 0.8 wt%.

Chromium (Cr): 0.3 to 0.6 wt%

[0042] Chromium is effective for enhancing hardenability together with manganese and enhances corrosion resistance of a steel. Thus, in the present disclosure, chromium may be added in an amount of 0.3 wt% or more. However, because chromium is a relatively expensive element compared to silicon and manganese and increases the C_{eq}, an upper limit of the Cr content may be controlled to 0.6 wt%.

Phosphorus (P): 0.015 wt% or less

[0043] Because phosphorus is an element segregated in grain boundaries to deteriorate toughness and deteriorate hydrogen delayed fracture resistance, it is desirable to remove P from steel materials as much as possible. Therefore, an upper limit thereof may be controlled to 0.015 wt%.

Sulfur (S): 0.01 wt% or less

[0044] Like phosphorus, sulfur is segregated in grain boundaries to deteriorate toughness and forms MnS to deteriorate hydrogen delayed fracture resistance, and thus it is desirable to remove S from steel materials as much as possible. Therefore, an upper limit of the S content may be controlled to 0.01 wt% in the present disclosure.

Aluminum (Al): 0.01 wt% or less

[0045] Aluminum, as a powerful deoxidizing element, may increase purity by removing oxygen from a steel. However, addition of Al causes formation of Al_2O_3, thereby deteriorating fatigue resistance. Therefore, an upper limit of the Al content may be controlled to 0.01 wt%.

Nitrogen (N): 0.005 wt% or less

[0046] Nitrogen binds to aluminum or vanadium contained in a steel to form coarse AlN or VN precipitates that are not melted during heat treatment. Therefore, an upper limit of the N content may be controlled to 0.005%.

Niobium (Nb): more than 0 wt% and 0.04 wt% or less

[0047] Niobium, as an element binding to carbon contained in a steel to form an Nb-based carbide, decreases grain size, thereby improving processibility. To improve processibility by grain refinement, the Nb content may be greater than 0 wt% in the present disclosure. However, when the Nb content is excessive, a coarse carbide formed thereby may deteriorate processibility, and thus niobium may be added in an amount of 0.04 wt% or less. More preferably, niobium may be added in an amount of 0.02 wt% or less to improve processibility.

[0048] The Nb-based carbide formed by adding Nb may be distributed in structures of the wire rod and the steel wire for an ultra-high strength spring according to the present disclosure. The size of the formed Nb-based carbide may be 20 nm or less. When the size of the formed Nb-based carbide is greater than 20 nm, there is a possibility that processibility may deteriorate. In addition, it is preferable that the Nb-based carbide is uniformly distributed at a density of 1000 grains/mm^2 or more. When the Nb-based carbide is distributed at a density less than 1000 grains/mm^2, there may be a possibility that grains are not sufficiently refined. In the above-described Nb-based carbide, Nb may be contained at 10 at% or more.

[0049] The remaining component of the composition of the present disclosure is iron (Fe). However, the composition may include unintended impurities inevitably incorporated from raw materials or surrounding environments. In the present disclosure, those impurities in addition to the above-described alloy components are not excluded. The impurities are not specifically mentioned in the present disclosure, as they are known to any person skilled in the art of manufacturing.

[0050] In addition, reasons for limitations on the alloy composition of the steel wire are identical to those for limitations on the alloy composition of the wire rod given above, and thus the reasons for limitations on the alloy composition of the steel wire will be omitted for descriptive convenience.

[0051] As well as liming the contents of alloying elements of the compositions of the wire rod and the steel wire of the present disclosure as described above, the relationships therebetween may further be limited as follows.

A value of Formula (1): 0.77 or more and 0.83 or less

[0052] In the present disclosure, the C_{eq} value is controlled to inhibit surface decarburization and formation of a low-temperature structure which are easily occurring during cooling after wire rod rolling. The C_{eq} value may be represented by Formula (1) below. In the present disclosure, the value of Formula (1) is controlled to 0.77 or more and 0.83 or less to inhibit surface decarburization and formation of a low-temperature structure.

$$(1)\ C + 1/6*Mn + 1/5*Cr + 1/24*Si$$

In Formula (1) above, C, Mn, Cr, and Si represent the content (wt%) of each element.

[0053] When the value of Formula (1) exceeds 0.83, surface decarburization may occur and a low-temperature structure may be formed. On the contrary, when the value of Formula (1) is less than 0.77, it is difficult to obtain a target strength.

[0054] Hereinafter, a method for manufacturing a wire rod for an ultra-high strength spring according to the present disclosure will be described in detail. The wire rod for an ultra-high strength spring according to the present disclosure is manufactured by homogenization heat-treating an ingot having the above-described alloy composition and satisfying the range of the value of Formula (1), wire rod rolling the ingot, and cooling the wire rod. Hereinafter, each step of the manufacturing process will be described.

[0055] In the present disclosure, the homogenization heat treating step may be performed in a heating furnace at a heating temperature of 900 to 1100°C within 180 minutes.

[0056] In the present disclosure, a finish rolling temperature of the wire rod rolling step may be from 730 to Ae3°C. By performing the finish rolling in a temperature range of 730 to Ae3°C, a main structure of the wire rod is transformed from austenite into ferrite. In other words, a main structure of the wire rod before finish rolling is austenite and a main structure of the wire rod after the finish rolling is ferrite.

[0057] In the wire rod rolling step of the present disclosure, grains may be refined by controlling rolling and sufficient processibility may be obtained by grain refinement. According to an embodiment, a strain of the wire rod rolling may be from 0.3 to 2.0. In the present disclosure, the strain is represented by the following equation.

$$\text{Strain} = -\ln(1-\text{reduction rate}/100)$$

[0058] In the equation above, reduction rate is a value obtained by (A-Ai)/A * 100 wherein A is an area of a cross-section of a wire rod perpendicular to the longitudinal direction before rolling the wire rod, and A_1 is an area of a cross-section of the wire rod perpendicular to the longitudinal direction after rolling the wire rod.

[0059] When the strain is less than 0.3 during the wire rod rolling, it is difficult to obtain sufficient grain refinement. When the strain exceeds 2.0, a manufacturing process is not appropriately performing due to too much processing amount. Therefore, according to the present disclosure, it is preferable to control the strain from 0.3 to 2.0.

[0060] Grain refinement may be obtained by wire rod rolling under the above-described conditions. According to an embodiment, an average grain size of austenite before finish rolling may be from 5 to 15 μm. Also, by reducing the average grain size of austenite before the finish rolling, an average grain size of ferrite in a final wire rod structure after subsequent finish rolling and cooling processes may also be reduced.

[0061] In the present disclosure, the cooling step may be performed by cooling the wire rod at a cooling rate of 3°C/s or less. When the cooling rate exceeds 3°C/s, it is difficult to inhibit formation of the low-temperature structure.

[0062] The wire rod for an ultra-high strength spring including the above-described alloy composition and manufactured by the above-described manufacturing method according to an embodiment may include pearlite and ferrite as micro-structures, e.g., 60% or more of pearlite in an area fraction and the remainder of ferrite according to an embodiment.

[0063] According to the present disclosure, formation of the low-temperature structure may be inhibited by the above-described alloy composition having a low C_{eq} and satisfying the range of the value of Formula (1). The wire rod for an ultra-high strength spring according to an embodiment of the present disclosure may hardly include a low-temperature structure on the cross-section perpendicular to the longitudinal direction. According to an embodiment, on the cross-section (cross-section C) perpendicular to the longitudinal direction, a sum of area fractions of bainite and martensite having a hardness of 400 Hv or more may be 1% or less. Meanwhile, the low-temperature structure refers to bainite and martensite in the present disclosure. The wire rod for an ultra-high strength spring of the present disclosure may have sufficient processibility by inhibiting formation of the low-temperature structure.

[0064] According to the present disclosure, the surface decarburization phenomenon may be inhibited by using the above-described alloy composition having a low C_{eq} and a low Si content and satisfying the range of the value of Formula (1). According to an embodiment, a ferrite decarburized layer of the wire rod may have a thickness of 1 μm or less.

[0065] According to the present disclosure, ferrite grains may be reduced in size by using the Nb-based carbide and controlling rolling. In the wire rod according to an embodiment of the present disclosure, an average grain size of ferrite may be 10 μm or less. The wire rod for an ultra-high strength spring according to the present disclosure may have sufficient processibility by grain refinement.

[0066] The wire rod for an ultra-high strength spring according to an embodiment of the present disclosure may have a tensile strength is 1200 MPa or less.

[0067] A steel wire for an ultra-high strength spring according to an embodiment of the present disclosure includes, in percent by weight (wt%), 0.55 to 0.65% of C, 0.5 to 0.9% of Si, 0.3 to 0.8% of Mn, 0.3 to 0.6% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.005% or less of N, more than 0% and 0.04% or less of Nb, and the remainder being Fe and unavoidable impurities, wherein a value of Formula (1) below is 0.77 or more and 0.83 or less, and the steel wire includes a tempered martensite in an area fraction of 90% or more.

[0068] Reasons for limitations on the alloy composition of the steel wire and the range of the value of Formula (1) are identical to those for limitations on the alloy composition of the wire and the range of the value of Formula (1) as described above, and thus descriptions thereof will be omitted for descriptive convenience.

[0069] Hereinafter, a method for manufacturing a steel wire for an ultra-high strength spring according to the present disclosure will be described in detail. The steel wire for an ultra-high strength spring according to the present disclosure is manufactured by drawing a wire rod including the above-described alloy composition and satisfying the range of the value of Formula (1), heating the wire rod, water quenching the wire rod at a high pressure, tempering the wire rod, and water quenching the wire rod. Hereinafter, each step of the manufacturing process will be described.

[0070] In the present disclosure, as a method for heating to the quenching temperature and a method for tempering, induction heat treatment is used such that the rapidly heated surface is sufficiently hardened during a subsequent water quenching. According to the present disclosure, a target ultra-high strength may be obtained by using the above-described alloy composition having a low C_{eq} and a low Si content and satisfying the range of the value of Formula (1) via induction heat treatment and water quenching while reducing the contents of alloying elements, compared to suspension springs for automobiles.

[0071] The drawing step of the present disclosure may be performed by drawing the wire rod including the above-described alloy composition and satisfying the range of the value of Formula (1) to a wire diameter of 15 mm or less applicable to suspension springs of motorcycles.

[0072] Then, in the heating step for QT heat treatment may be performed by heating the drawn steel wire to a quenching temperature of 900 to 1000°C within 10 seconds and maintaining the temperature for 5 to 60 seconds, thereby transforming the structure of the steel wire into austenite. When the heating time to the target temperature of 900 to 1000°C exceeds 10 seconds, it is difficult to obtain desired physical properties since grains grow. When the maintaining time is less than 5 seconds, the pearlite structure may not be transformed into austenite. When the maintaining time exceeds 60 seconds, coarse grains may be formed. Therefore, it is preferable to control the maintaining time from 5 to 60 seconds.

[0073] Also, as a result of rapidly heating the drawn steel wire by induction heating, the average grain size of austenite of the austenized steel wire may be reduced to 10 μm or less. In this step, as a results of controlling grains of austenite to be fine, grains of the final steel wire for an ultra-high strength spring that are manufactured by subsequent water quenching at a high pressure, tempering, and water quenching may also be controlled to be fine. Accordingly, the steel wire for an ultra-high strength spring according to the present disclosure has excellent processability due to fine grains and may be manufactured into suspension springs of motorcycles as being cold-formed at room temperature.

[0074] In the present disclosure, the water quenching step performed at a high pressure is a step of transforming the main structure of the steel wire from austenite into martensite and may be performed at a high pressure enough to removing a boiling film of the austenitized steel wire in the previous step. In this case, when oil quenching is performed instead of the water quenching, the target strength cannot be obtained due to a low C_{eq} and a low Si content. In addition, unless the high pressure enough to remove the boiling film is used during water quenching, the probability of occurrence of quenching cracks increases, and thus it is preferable to perform water quenching at a temperature as high as possible. In addition, the surface of the steel wire may be sufficiently hardened by rapidly cooling using water in this step after induction heating to the quenching temperature in the above-described heating step. The cooling rate according to an embodiment during the water quenching may be 100°C/s or more.

[0075] In the present disclosure, the tempering step is a step of heating martensite, as a main structure of the water-quenched steel wire, into a tampered martensite. The tempering step may be performed by heating the wire rod to a temperature of 400 to 500°C within 10 seconds and maintaining the temperature for 30 seconds. When the tempering temperature is less than 400°C, toughness cannot be obtained so that processibility deteriorates and the risk of damage to products increases. When the tempering temperature exceeds 500°C, strength may deteriorate. Therefore, the tempering temperature is controlled to the above-described temperature range. In addition, when the heating to the above-described temperature range is not performed within 10 seconds during tempering, coarse carbides are formed, thereby deteriorating toughness. Thus, it is preferable to rapidly heat within 10 seconds.

[0076] Then, the tempered steel wire is water-quenched to room temperature.

[0077] The steel wire for springs including the above-described alloy composition, satisfying the range of the value of Formula (1), and manufactured under the above-described manufacturing conditions, may include a tempered martensite in an area fraction of 90% or more.

[0078] In addition, in the steel wire for an ultra-high strength spring according to an embodiment of the present disclosure, an Nb-based carbide having a size of 20 nm or less may be distributed at a density of 1000 grains/mm^2 or more.

[0079] In addition, in the steel wire for an ultra-high strength spring according to an embodiment of the present disclosure, an average grain size of spherical austenite may be 10 μm or less. In this regard, the spherical austenite refers to an austenite structure of the steel wire after the step of heating the drawn steel wire of the present disclosure for QT heat treatment.

[0080] In addition, the steel wire for an ultra-high strength spring according to an embodiment of the present disclosure has a wire diameter of 15 mm or less, which is suitable for a steel wire for suspension springs for motorcycles.

[0081] In addition, the steel wire for an ultra-high strength spring according to an embodiment of the present disclosure may have a strength of 1700 MPa or more, which is an ultra-high strength required for suspension springs of motorcycles.

[0082] In addition, the steel wire for an ultra-high strength spring according to an embodiment of the present disclosure may have a reduction in area (RA) of 35% or more, which is high ductility, and thus may be manufactured into suspension spring of motorcycles by cold-rolling at room temperature. According to the present disclosure, austenite grains may be reduced in size before finish rolling of the wire rod rolling by adding Nb and thus the reduction in area (RA) may further be increased. The steel wire for an ultra-high strength spring according to an embodiment of the present disclosure may have a reduction in area (RA) of 45% or more.

[0083] Hereinafter, the present disclosure will be described in more detail through examples. However, it is necessary to note that the following examples are only intended to illustrate the present disclosure in more detail and are not intended to limit the scope of the present disclosure. This is because the scope of the present disclosure is determined by matters described in the claims and able to be reasonably inferred therefrom.

Examples

[0084] Materials including alloy compositions shown in Table 1 were cast to an ingot, homogenization heat-treated at 1100°C, wire rod-rolled to a final thickness of 12 mm while lowering the temperature from 1030°C to 750°C, and cooled at a cooling rate of 3°C/s, thereby preparing a wire rod.

Table 1

	Alloying element (wt%)								
	C	Si	Mn	Cr	P	S	Al	N	Nb
Comparative Example 1	0.60	1.50	0.60	0.40	0.011	0.004	<0.003	<0.005	-
Comparative Example 2	0.45	0.80	0.80	0.60	0.01	0.005	<0.003	<0.005	-
Comparative Example 3	0.60	0.80	0.60	0.40	0.01	0.004	<0.003	<0.005	-
Inventive Example 1	0.60	0.80	0.60	0.40	0.009	0.005	<0.003	<0.005	0.02
Inventive Example 2	0.60	0.60	0.30	0.60	0.011	0.005	<0.003	<0.005	0.02

[0085] The results of Table 2 below show physical properties of wire rods prepared according to the above-described process. The area fraction of the low-temperature structure of Table 2 indicates a sum of area fractions of bainite and martensite on the cross-section of the wire rod perpendicular to the longitudinal direction.

[0086] The AGS of Table 2 refers to an average grain size of austenite before finish rolling during the wire rod rolling step and was measured according to the ASTM E112 standard.

[0087] The thickness of the ferrite decarburized layer indicates a thickness of a layer formed only of ferrite on the surface of a steel after the wire rod rolling by decarburization, and the thickness of the total decarburized layer is measured a vertical distance from the surface of the decarburized layer to a point where a concentration of carbon is the same as that of carbon of a matrix.

Table 2

Example	Formu la (1)	Area fraction of low-temperature structure (%)	AGS (μm)	Hard ness (Hv)	Tensile strength (MPa)	Thickness of ferrite decarburiz ed layer (μm)	Thickness of total decarburiz ed layer (μm)
Comparative Example 1	0.803	0	15	318	1030	22	60.2
Comparative Example2	0.737	0	19	235	762	-	22.8
Comparative Example 3	0.813	0	18	290	942	-	25.1
Inventive Example 1	0.813	0	8	291	950	-	30.1
Inventive Example 2	0.795	0	7	288	930	-	15.2

[0088] The wire rod of Table 2 was drawn to a steel wire having a diameter of 10 mm, heated, and water-quenched at a high pressure. After the high-pressure water quenching, the steel wire was tempered and water-quenched to prepare a final steel wire for an ultra-high strength spring. The heating temperature in Table 3 indicates a temperature at which the steel wire was heated after drawing, and the tempering temperature indicates a temperature at which the steel wire is tempered after the high-pressure water quenching. RA represents a reduction in area.

Table 3

Example	Formul a (1)	Heating temperatur e (°C)	Tempering temperature (°C)	Hardness (Hv)	RA (%)	Tensile strength (MPa)
Comparative Example 1	0.803	950	430	573	47	1920
Comparative Example 2	0.737	950	430	498	43	1670

(continued)

Example	Formula (1)	Heating temperature (°C)	Tempering temperature (°C)	Hardness (Hv)	RA (%)	Tensile strength (MPa)
Comparative Example 3	0.813	950	430	545	40	1815
Inventive Example 1	0.813	950	430	550	45	1820
Inventive Example 2	0.795	950	430	540	47	1800

[0089] Referring to Tables 1 to 3, because Inventive Examples 1 and 2 satisfied the alloy composition, the value of Formula (1), and the manufacturing conditions according to the present disclosure, formation of a low-temperature structure and a ferrite decarburized layer was inhibited in the wire rod, and grain refinement of austenite was obtained before finish rolling during the wire rod rolling by adding Nb. In addition, as shown in Table 3, the tensile strength was 1700 MPa or more and the reduction in area was 35% or more. On the contrary, in Comparative Example 1, a thick ferrite decarburized layer was formed due to the high Si content. In Comparative Example 2, a target strength of 1700 MPa or more could not be obtained because the value of Formula (1) was lower than 0.77. In Comparative Example 3, a desired average grain size of austenite could not be obtained due to coursing of grains because Nb was not added thereto. Accordingly, the reduction in area (RA) was lower than the materials to which Nb was added.

[0090] While the present disclosure has been particularly described with reference to exemplary embodiments, it should be understood by those of skilled in the art that various changes in form and details may be made without departing from the spirit and scope of the present disclosure.

[Industrial Applicability]

[0091] The wire rod for an ultra-high strength spring according to the present disclosure may be applicable to suspension springs of various means of transportation such as automobiles and motorcycles or to springs used in various industrial fields.

Claims

1. A wire rod for an ultra-high strength spring comprising, in percent by weight (wt%), 0.55 to 0.65% of C, 0.5 to 0.9% of Si, 0.3 to 0.8% of Mn, 0.3 to 0.6% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.005% or less ofN, more than 0% and 0.04% or less of Nb, and the remainder being Fe and unavoidable impurities, and satisfying a value of Formula (1) below being 0.77 or more and 0.83 or less:

$$(1)\ C + 1/6*Mn + 1/5*Cr + 1/24*Si$$

(wherein in Formula (1), C, Mn, Cr, and Si represent the content (wt%) of each element).

2. The wire rod according to claim 1, wherein, on a cross-section perpendicular to a longitudinal direction, a sum of area fractions of bainite and martensite having a hardness is 400 Hv or more is 1% or less.

3. The wire rod according to claim 1, wherein a ferrite decarburized layer has a thickness of 1 μm or less.

4. The wire rod according to claim 1, wherein an average grain size of ferrite is 10 μm or less.

5. The wire rod according to claim 1, wherein an Nb-based carbide having a size of 20 nm or less is distributed at a density of 1000 grains/mm^2 or more.

6. The wire rod according to claim 1, wherein a tensile strength is 1200 MPa or less.

7. A method for manufacturing a wire rod for an ultra-high strength spring, the method comprising:

homogenization heat-treating an ingot including, in percent by weight (wt%), 0.55 to 0.65% of C, 0.5 to 0.9% of Si, 0.3 to 0.8% of Mn, 0.3 to 0.6% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.005% or less of N, more than 0% and 0.04% or less of Nb, and the remainder being Fe and unavoidable impurities, and satisfying a value of Formula (1) below being 0.77 or more and 0.83 or less, at a heating temperature of 900 to 1100°C within 180 minutes;
wire rod rolling the ingot at a finish rolling temperature of 730 to Ae3°C; and
cooling the wire rod at a cooling rate of 3°C/s or less:

$$(1)\ C + 1/6*Mn + 1/5*Cr + 1/24*Si$$

(wherein in Formula (1), C, Mn, Cr, and Si represent the content (wt%) of each element).

8. The method according to claim 7, wherein a strain in the wire rod rolling is from 0.3 to 2.0.

9. The method according to claim 7, wherein an average grain size of austenite before finish rolling in the wire rod rolling is from 5 to 15 μm.

10. A steel wire for an ultra-high strength spring comprising, in percent by weight (wt%), 0.55 to 0.65% of C, 0.5 to 0.9% of Si, 0.3 to 0.8% of Mn, 0.3 to 0.6% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.005% or less ofN, more than 0% and 0.04% or less of Nb, and the remainder being Fe and unavoidable impurities, and satisfying a value of Formula (1) below being 0.77 or more and 0.83 or less,

wherein the steel wire comprises a tempered martensite in an area fraction of 90% or more:

$$(1)\ 0.77 \leq C + 1/6*Mn + 1/5*Cr + 1/24*Si \leq 0.83$$

(wherein in Formula (1), C, Mn, Cr, and Si represent the content (wt%) of each element).

11. The steel wire according to claim 10, wherein an Nb-based carbide having a size of 20 nm or less is distributed at a density of 1000 grains/mm^2 or more.

12. The steel wire according to claim 10, wherein an average grain size of spherical austenite is 10 μm or less.

13. The steel wire according to claim 10, wherein a wire diameter is 15 mm or less.

14. The steel wire according to claim 10, wherein a strength is 1700 MPa or more.

15. The steel wire according to claim 10, wherein a reduction in area is 35% or more.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2020/008091

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/26(2006.01)i; **C21D 8/06**(2006.01)i; **B21B 1/16**(2006.01)i; **B21B 3/00**(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)

C22C 38/26; C21D 1/18; C21D 8/06; C22C 38/00; C22C 38/02; C22C 38/34; F16F 1/02; B21B 1/16; B21B 3/00

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

Korean utility models and applications for utility models: IPC as above
Japanese utility models and applications for utility models: IPC as above

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

eKOMPASS (KIPO internal) & keywords: 고강도(high strength), 스프링용(for spring), 강선(steel wire rod), 베이나이트(bainite) 및 마르텐사이트(martensite)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 2019-178405 A (JFE STEEL CORP.) 17 October 2019. See paragraphs [0024]-[0035] and claims 1 and 2.	1-9 10-15
Y	JP 6447799 B1 (NIPPON STEEL CORP.) 14 December 2018. See paragraphs [0053]-[0062].	10-15
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☑ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
05 October 2020	**06 October 2020**
Name and mailing address of the ISA/KR **Korean Intellectual Property Office** **Government Complex-Daejeon Building 4, 189 Cheongsa-ro, Seo-gu, Daejeon 35208** Facsimile No. **+82-42-481-8578**	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
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