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(71) Applicant: **POSCO Co., Ltd**
Pohang-si, Gyeongsangbuk-do 37859 (KR)

(72) Inventors:
- **LEE, Junmo**
Pohang-si, Gyeongsangbuk-do 37834 (KR)
- **CHOI, Seokhwan**
Pohang-si, Gyeongsangbuk-do 37904 (KR)
- **CHOI, Myungsoo**
Pohang-si, Gyeongsangbuk-do 37669 (KR)

(74) Representative: **Nederlandsch Octrooibureau**
P.O. Box 29720
2502 LS The Hague (NL)

(54) **WIRE ROD AND STEEL WIRE FOR SPRING, SPRING WITH IMPROVED STRENGTH AND FATIGUE LIMIT, AND METHOD FOR MANUFACTURING SAME**

(57) Disclosed are a wire rod and a steel wire for a spring, a spring with improved strength and fatigue limit, and a method for manufacturing the same.

The disclosed wire rod for a spring with improved strength and fatigue limit according to an embodiment includes, in percent by weight (wt%): 0.6 to 0.7% of C, 2.0 to 2.5% of Si, 0.2 to 0.7% of Mn, 0.9 to 1.5% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.01% or less of N, 0.25% or less of Mo, 0.25% or less of W, 0.05% to 0.2% of V, 0.05% or less of Nb, and the balance of Fe and unavoidable impurities, wherein Mn+Cr≤1.8% and 0.05 at%≤Mo+W≤0.15 at% may be satisfied.

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Description

[Technical Field]

[0001] The present disclosure relates to a wire rod and a steel wire for a spring, a spring with improved strength and fatigue limit, and a method for manufacturing the same, and more particularly, to a wire rod and a steel wire for a spring and a spring having an ultra-high strength at a level of 2,200 MPa and excellent workability, allowing easy nitriding at a high temperature, and having improved nitriding properties and fatigue limit, and a method for manufacturing the same.

[Background Art]

[0002] To meet continuous demands for lightweight automotive parts with the development of lightweight vehicles, springs used in transmissions and engine valves of vehicles are also required to have high strength. However, as strength of spring materials increases, wire diameter decreases to increase sensitivity to inclusions, thereby reducing fatigue limit. That is, there are limits to increase fatigue limit by increasing strength. To overcome this, spring manufacturers attempted to increase fatigue limit of materials for springs by increasing surface hardness while maintaining strength by nitriding.

[0003] Although nitriding for other parts is generally performed at a temperature above 500°C, nitriding for steels for springs is performed at a temperature of 420 to 460°C to prevent a decrease in strength and for a long time over 10 hours to obtain a sufficient nitrogen penetration depth.

[0004] Since a tempering heat treatment temperature of common steels for springs is 450°C is below, heat treatment for a long time at a temperature of 420 to 450°C may decrease strength of most of the springs, and thus a highly alloying material including an element capable of improving softening resistance by forming a carbide should be used. However, in the case of using a large amount of a carbide-forming element such as Mo and V, a decrease in strength may be inhibited during nitriding, but a low-temperature structure may be formed by central segregated region and a problem of decreasing a reduction of area may be caused.

[0005] Also, because a high-temperature heat treatment process is repeated while processing a spring material, a problem may occur in controlling a prior austenite grain size (PAGS) and a technique of controlling a carbide is required during the heat treatment.

[0006] Meanwhile, spring manufacturers require to shorten a processing time of nitriding by performing nitriding at a temperature as high as possible to shorten a nitriding time and also requires a high strength wire rod not causing a problem in productivity in the field.

[0007] Therefore, there is a need to develop a wire rod and a steel wire having excellent quality such as strength and workability and improved nitriding properties and fatigue limit.

[0008] (Patent Document 0001) Korean Patent Laid-open Publication No. 10-2000-0043776 (Published on July 15, 2000)

[Disclosure]

[Technical Problem]

[0009] To solve the problems as described above, provided is a wire rod, a steel wire, and a spring each having excellent strength and workability, allowing easy nitriding at a high temperature, and having improved nitriding properties and fatigue limit, and a method for manufacturing the same.

[Technical Solution]

[0010] In accordance with an aspect of the present disclosure, a wire rod for a spring with improved strength and fatigue limit includes, in percent by weight (wt%), 0.6 to 0.7% of C, 2.0 to 2.5% of Si, 0.2 to 0.7% of Mn, 0.9 to 1.5% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.01% or less of N, 0.25% or less of Mo, 0.25% or less of W, 0.05% to 0.2% of V, 0.05% or less of Nb, and the balance of Fe and unavoidable impurities, wherein Mn+Cr≤ 1.8% is satisfied, 0.05 at%≤Mo+W≤0.15 at% is satisfied, a proportion (wt%) of an area satisfying one or more of C > 0.85%, Si > 3.0%, Mn > 0.8%, and Cr > 2.0% is 10% or less within an area of 1 mm^2 of a central region of a cross-section perpendicular to a lengthwise direction.

[0011] In this regard, the wire rod may include, in an area fraction, 80% or more of a pearlite structure and the balance of a bainite structure or a martensite structure.

[0012] In this regard, a prior austenite average grain size may be 20 μm or less.

[0013] In this regard, the number of a carbonitride having a maximum diameter of 15 μm or more distributed in a cross-section parallel to a lengthwise direction within a surface depth of 1 mm may be less than 2 per cm^2.

[0014] In this regard, a tensile strength may be 1,400 MPa or less, and a reduction of area may be 35% or more.

[0015] In accordance with another aspect of the present disclosure, a method for manufacturing a wire rod for a spring with improved strength and fatigue limit includes: preparing a bloom by continuously casting a molten steel including, in percent by weight (wt%), 0.6 to 0.7% of C, 2.0 to 2.5% of Si, 0.2 to 0.7% of Mn, 0.9 to 1.5% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.01% or less of N, 0.25% or less of Mo, 0.25% or less of W, 0.05% to 0.2% of V, 0.05% or less of Nb, and the balance of Fe and unavoidable impurities; heating the bloom at a temperature of 1,200°C or above and rolling the bloom to prepare a billet; heating the billet at a temperature of 1,030°C or above and rolling the billet at a temperature of 1,000°C below to prepare a wire rod; coiling the rolled wire rod at a temperature of 800 to 900°C; and cooling the coiled wire rod at a seed of 0.5 to 2°C/sec.

[0016] In this regard, the continuously casting process may include performing soft reduction with a total rolling reduction 20 mm or more.

[0017] In this regard, the soft reduction may be performed to allow each roll to roll by reducing 4 mm or less and may have a cumulative rolling reduction of 60% or more at a solidification fraction of 0.6 or more.

[0018] In accordance with another aspect of the present disclosure, a steel wire for a spring with improved strength and fatigue limit includes, in percent by weight (wt%), 0.6 to 0.7% of C, 2.0 to 2.5% of Si, 0.2 to 0.7% of Mn, 0.9 to 1.5% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.01% or less of N, 0.25% or less of Mo, 0.25% or less of W, 0.05% to 0.2% of V, 0.05% or less of Nb, and the balance of Fe and unavoidable impurities, wherein Mn+Cr≤ 1.8% is satisfied, 0.05 at%≤Mo+W≤0.15 at% is satisfied, and the steel wire includes, in an area fraction, 85% or more of a tempered martensite structure and the balance of an austenite structure.

[0019] In this regard, a prior austenite average grain size may be 15 μm or less.

[0020] In this regard, the number of a carbonitride having a maximum diameter of 15 μm or more distributed in a cross-section parallel to the lengthwise direction within a surface depth of 1 mm may be less than 2 per cm^2.

[0021] In this regard, the number of carbides in an area of 100 μm^2 may be from 10 to 50, the maximum diameter of the carbide may be from 5 to 50 nm, and a content of V or Nb may be 10 at% or more.2

[0022] In this regard, a tensile strength may be 2,100 MPa or more, and a reduction of area may be 45% or more.

[0023] In accordance with another aspect of the present disclosure, a method for manufacturing a steel wire for a spring with improved strength and fatigue limit includes: performing LA heat treatment on the wire rod; drawing the LP heat-treated wire rod to prepare a steel wire; and performing QT heat treatment on the steel wire, wherein the LP heat treatment includes: a primary austenizing process of heating to a temperature of 950 to 1100°C within 3 minutes and maintaining for 3 minutes or less; and a process of passing the primarily austenized wire rod through a Pb bath at a temperature of 650 to 700°C within 3 minutes.

[0024] In this regard, in the LP heat treatment, a pearlite transformation completion time may be less than 130 seconds.

[0025] In this regard, the method may further include performing LA heat treatment on the wire rod before the LP heat treatment, wherein the LA heat treatment may further include performing heat treatment at a temperature of 650 to 750°C; and performing acid pickling.

[0026] In this regard, the QT heat treatment may include a secondary austenizing process of heating to a temperature of 900 to 1000°C within 3 minutes and maintaining for 3 minutes or less; and a primary oil quenching process performed at 70°C or below; a tempering process of heating to a temperature of 450 to 550°C within 3 minutes and maintaining for 3 minutes or less; and a secondary oil quenching process performed at 70°C or below.

[0027] In accordance with another aspect of the present disclosure, a spring with improved strength and fatigue limit may include, in percent by weight (wt%), 0.6 to 0.7% of C, 2.0 to 2.5% of Si, 0.2 to 0.7% of Mn, 0.9 to 1.5% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.01% or less of N, 0.25% or less of Mo, 0.25% or less of W, 0.05% to 0.2% of V, 0.05% or less of Nb, and the balance of Fe and unavoidable impurities, wherein Mn+Cr≤1.8% and 0.05 at%≤Mo+W≤0.15 at% are satisfied, and a fatigue limit which withstands repeated stress more than 10 million times is 700 MPa or more.

[0028] In accordance with another aspect of the present disclosure, a method for manufacturing a spring with improved strength and fatigue limit includes: cold forming the steel wire according to an embodiment of the present disclosure in a spring form; performing stress-relieving heat treatment on the formed spring; and nitriding the resultant.

[0029] In addition, according to the method for manufacturing a spring with improved strength and fatigue limit, the fatigue limit may increase by 10% or more after nitriding.

[Advantageous Effects]

[0030] According to an aspect of the present disclosure, provided are a wire rod, a steel wire, and a spring capable of inhibiting formation of a low-temperature structure at a central region by reducing central segregation, and obtaining an excellent reduction of area and a tensile strength of 2,200 MPa or more, and a method for manufacturing the same.

[0031] According to another aspect of the present disclosure, provided are a wire rod, steel wire, and a spring having improved nitriding properties and fatigue limit by controlling the grain size and the number of precipitates, and a method for manufacturing the same.

[Best Mode]

[0032] A wire rod for a spring with improved strength and fatigue limit according to the present disclosure includes, in percent by weight (wt%), 0.6 to 0.7% of C, 2.0 to 2.5% of Si, 0.2 to 0.7% of Mn, 0.9 to 1.5% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.01% or less of N, 0.25% or less of Mo, 0.25% or less of W, 0.05% to 0.2% of V, 0.05% or less of Nb, and the balance of Fe and unavoidable impurities, wherein Mn+Cr≤1.8% and 0.05 at%≤Mo+W≤0.15 at% are satisfied, and a proportion (wt%) of an area satisfying one or more of C > 0.85%, Si > 3.0%, Mn > 0.8%, and Cr > 2.0% is 10% or less within an area of 1 mm^2 of a central region of a cross-section perpendicular to a lengthwise direction.

[Modes of the Invention]

[0033] 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.

[0034] 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, processes, functions, components, or combinations thereof disclosed in the specification, and are not intended to preclude the possibility that one or more other features, processes, functions, components, or combinations thereof may exist or may be added.

[0035] 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.

[0036] 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.

[0037] A wire rod for a spring with improved strength and fatigue limit according to an embodiment of the present disclosure includes, in percent by weight (wt%), 0.6 to 0.7% of C, 2.0 to 2.5% of Si, 0.2 to 0.7% of Mn, 0.9 to 1.5% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.01% or less of N, 0.25% or less of Mo, 0.25% or less of W, 0.05% to 0.2% of V, 0.05% or less of Nb, and the balance of Fe and unavoidable impurities.

[0038] Hereinafter, reasons for numerical limitations on the contents of the alloying elements will be described. Hereinafter, the unit is wt% unless otherwise stated.

[0039] A content of C is from 0.6 to 0.7%.

[0040] C is an element increasing strength of a material and may be added in an amount of 0.6% or more to obtain sufficient strength of the material. However, an excess of C may cause a significant deterioration in impact properties after quenching & tempering (QT) heat treatment and an increase in the possibility of formation of a low-temperature structure during a manufacturing process of wire rods, thereby deteriorating the quality of the wire rods. Also, if the C content is excessive, a heat treatment time of LP heat treatment, one of steel wire-manufacturing processes, significantly increases to reduce productivity. In consideration thereof, an upper limit of the C content may be controlled to 0.7%.

[0041] A content of Si is from 2.0 to 2.5%.

[0042] Si used for deoxidization of steels is also effective for obtaining strength by solid solution strengthening, and may be added in an amount of 2.0% or more to inhibit a decrease in strength during nitriding and to improve deformation resistance of a spring. However, an excess of Si may cause surface decarburization and deterioration of workability of a material. In consideration thereof, an upper limit of the Si content may be controlled to 2.5%.

[0043] A content of Mn is from 0.2 to 0.7%.

[0044] Mn, as a hardenability-enhancing element, may be added in an amount of 0.2% or more to obtain hardenability of a material, form a high strength tempered martensite structure, and make S harmless by fixing S. However, an excess of Mn may cause deterioration of quality due to segregation. In consideration thereof, an upper limit of the Mn content may be controlled to 0.7%.

[0045] A content of Cr is from 0.9 to 1.5%.

[0046] Cr is a hardenability-enhancing element together with Mn and may be added in an amount of 0.9% or more to enhance softening resistance of a steel. However, an excess of Cr may cause a significant decrease in toughness of a steel wire and promote formation of a low-temperature structure while cooling a wire rod. In consideration thereof, an upper limit of the Cr content may be controlled to 1.5%.

[0047] A content of P is 0.015% or less.

[0048] P is an element segregated in grain boundaries resulting in deterioration of toughness and deterioration of hydrogen delayed fracture resistance of materials, and thus it is desirable to remove P from steel materials. In consideration thereof, an upper limit of the P content may be controlled to 0.015%.

[0049] A content of S is 0.01% or less.

[0050] As well as P, S may be segregated in grain boundaries resulting in deterioration of toughness and deterioration of hydrogen delayed fracture resistance of materials by forming MnS. In consideration thereof, an upper limit of the S content may be controlled to 0.01%.

[0051] A content of Al is 0.01% or less.

[0052] Although Al, as a powerful deoxidizing element, increases purity by removing oxygen from a steel, Al_2O_3 inclusions may be formed thereby, resulting in a decrease in fatigue resistance. In consideration thereof, an upper limit of the Al content may be controlled to 0.01%.

[0053] A content of N is 0.01% or less.

[0054] Although N is an impurity, N binds to Al or V to form crude AlN or VN precipitates that do not melt during heat treatment. In consideration thereof, an upper limit of the N content may be controlled to 0.01%.

[0055] A content of Mo is 0.25% or less.

[0056] Among materials for nitriding, Mo is an element improving softening resistance and forming a carbide with V to improve strength during temperature. In addition, Mo forms a MC carbide and maintain strength of a material even after a heat treatment for a long time. However, an excess of Mo inhibits formation of a pearlite structure, and thus quality of the wire rod may deteriorate due to formation of a low-temperature structure after rolling the wire rod. In addition, an excess of Mo inhibits perlite transformation during LP heat treatment before drawing to increase a pearlite transformation time, resulting in a significant decrease in productivity. In consideration thereof, an upper limit of the Mo content may be controlled to 0.25%.

[0057] A content of W is 0.25% or less.

[0058] Like Mo, W, as an element improving softening resistance together with Mo among the materials for nitriding, forms a MC carbide to maintain strength of a material even after heat treatment for a long time. However, an excess of W may inhibit formation of pearlite and promote formation of a low-temperature structure in the wire rod. In consideration thereof, an upper limit of the W content may be controlled to 0.25%.

[0059] A content of V is from 0.05 to 0.2%.

[0060] V, as an element improving softening resistance, together with Mo, among the materials for nitriding, forms a carbide to increase strength during tempering and may maintain strength even after nitriding is performed for a long time. In addition, V, unlike Mo and W, has a high solid solution temperature of a carbide serving to maintain a prior austenite grain size. In addition, because V accelerates pearlite transformation, formation of a low-temperature structure may be inhibited while the wire rod is produced, a thermostatic transformation time may be reduced during LP heat treatment, and productivity may be improved during a steel wire manufacturing process, and thus V may be added in an amount of 0.05% or more. However, if the V content is excessive, a crude carbonitride may be formed during a wire rod producing process, and temperature should be raised by heating while rolling the wire rod. In consideration thereof, an upper limit of the V content may be controlled to 0.2%.

[0061] A content of Nb is 0.05% or less.

[0062] Nb, as a carbonitride-forming element, has a higher solid solution temperature than that of V to have superior effects on controlling the prior austenite grain size to V. However, if the Nb content is excessive, a problem of increasing the prior austenite grain size may occur. In consideration thereof, an upper limit of the Nb content may be controlled to 0.05%, and the addition of Nb may be omitted in the case where the prior austenite grain size is controlled during the manufacturing process.

[0063] 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, and thus addition of other alloy components is 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.

[0064] Meanwhile, the wire rod with improved strength and fatigue limit according to an embodiment of the present disclosure may satisfy, in percent by weight (wt%), $Mn+Cr \leq 1.8\%$.

[0065] If the sum of Mn and Cr exceeds 1.8%, a low-temperature structure such as bainite or martensite may be formed during a process of cooling the wire rod, and a pearlite transformation completion time may increase during LP heat treatment. In addition, if the sum of Mn and Cr exceeds 1.8%, carbon equivalent (Ceq) significantly increases to limit the amounts of W and Mo, and thus a decrease in strength of a material may be prevented during nitriding. In addition, if the carbon equivalent (Ceq) increases, the pearlite transformation time increases failing to obtain a complete pearlite structure during the process of cooling the wire rod and the LP heat treatment time increases to cause a decrease in productivity.

[0066] In addition, the wire rod with improved strength and fatigue limit according to an embodiment of the present disclosure may satisfy 0.05 at%≤Mo+W≤0.15 at%. In this regard, at% refers to atomic weight percent.

[0067] If the sum of at% of Mo and W is less than 0.05 at%, a decrease in strength cannot be inhibited during nitriding, and thus a steel material cannot be used as a nitrided steel. On the contrary, if the sum of at% of Mo and W exceeds 0.15 at%, the carbon equivalent increases to increase the pearlite transformation time, thereby causing a problem of decreasing productivity.

[0068] Meanwhile, the reason for controlling by at% is to control the ratio of Mo and W to the carbide to 1: 1 because Mo and W contribute to increase strength by forming a carbide in the form of MC (wherein M=Mo or W and C=carbon).

[0069] In addition, in the wire rod according to an embodiment of the present disclosure, the pearlite transformation completion time during the lead patenting (LP) heat treatment may be less than 130 seconds. In this regard, the LP heat treatment process may include a process of heating at a temperature of 950 to 1100°C and rapidly cooling to a temperature of 650 to 750°C. If the pearlite transformation completion time exceeds 130 seconds during the LP heat treatment, a problem of decreasing productivity may occur.

[0070] In addition, the wire rod with improved strength and fatigue limit according to an embodiment of the present disclosure may include a pearlite structure in an area fraction of 80% or more.

[0071] Also, the wire rod with improved strength and fatigue limit according to an embodiment of the present disclosure may have a prior austenite average grain size of 20 μm or less. When the prior austenite average grain size exceeds 20 μm, the time for the LP heat treatment process increases and a problem of deteriorating workability of the wire rod may occur.

[0072] In addition, in the wire rod with improved strength and fatigue limit according to an embodiment of the present disclosure, a proportion (wt%) of an area satisfying one or more of C > 0.85%, Si > 3.0%, Mn > 0.8%, and Cr > 2.0% may be 10% or less within an area of 1 mm^2 of a central region of a cross-section perpendicular to a lengthwise direction.

[0073] When the above-described proportion of the area exceeds 10%, deterioration of quality of a material such as formation of a low-temperature structure due to central segregation may be caused, and a reduction of area (RA) decreases after manufacturing a steel wire to cause deterioration of workability thereby increasing a frequency of breakage while processing a spring. In addition, when the above-described area exceeds 10%, the carbide effect may decrease due to concentration of carbide forming elements at the center.

[0074] In addition, in the wire rod with improved strength and fatigue limit according to an embodiment of the present disclosure, the number of carbonitrides having a maximum diameter of 15 μm or more distributed in a cross-section parallel to the lengthwise direction within a surface depth of 1 mm may be less than 2 per cm^2.

[0075] In the case where a carbonitride having a diameter of 15 μm or more is present on the surface of the wire rod, fatigue breakage may occur in a material. Therefore, it may be preferable that the number of carbonitrides having a maximum diameter of 15 μm or more existing in a cross-section parallel to the lengthwise direction within a surface depth of 1 mm may be less than 2 per cm^2.

[0076] In addition, the wire rod with improved strength and fatigue limit according to an embodiment of the present disclosure may have a tensile strength of 1,400 MPa or less and a reduction of area (RA) of 35% or more.

[0077] Hereinafter, a method for manufacturing a wire rod for a spring with improved strength and fatigue limit according to an embodiment of the present disclosure will be described.

[0078] A method for manufacturing a wire rod for a spring with improved strength and fatigue limit according to an embodiment of the present disclosure includes: preparing a bloom by continuously casting a molten steel including, in percent by weight (wt%), 0.6 to 0.7% of C, 2.0 to 2.5% of Si, 0.2 to 0.7% of Mn, 0.9 to 1.5% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.01% or less of N, 0.25% or less of Mo, 0.25% or less of W, 0.05% to 0.2% of V, 0.05% or less of Nb, and the balance of Fe and unavoidable impurities; heating the bloom at a temperature of 1,200°C or above and rolling the bloom to prepare a billet; heating the billet at a temperature of 1,030°C or above and rolling the billet at a temperature of 1,000°C below to prepare a wire rod; coiling the rolled wire rod at a temperature of 800 to 900°C; and cooling the coiled wire rod at a seed of 0.5 to 2°C/sec.

[0079] Reasons for numerical limitations on the contents of alloying elements are as described above, and hereinafter, processes of the manufacturing method thereof will be described in more detail.

[0080] According to an embodiment of the present disclosure, the continuously casting process may include performing soft reduction with a total rolling reduction 20 mm or more.

[0081] A method of casting a slab having a unsolidified layer in the final solidification stage in a continuous casting machine while gradually compressing the slab with a total rolling reduction and at a compressing rate approximately corresponding to a sum of the amount of solidification shrinkage and the amount of thermal shrinkage by passing the slab through a collection of reduction rolls is referred to as soft reduction. In this regard, the total rolling reduction refers to an amount of rolling reduction from the start to the end of the compression. When the total rolling reduction is less than 20 mm, it is difficult to obtain a segregation-removing effect by soft reduction, and thus the total rolling reduction of the soft reduction may be controlled to 20 mm or more to minimize segregation of the wire rod.

[0082] In addition, according to an embodiment of the present disclosure, the soft reduction may be performed such that each roll reduces 4 mm or less, and a cumulative rolling reduction is 60% or more at a solidification fraction of 0.6 or more. The solidification fraction refers to a ratio of a weight of sold-phase molten steel to a total weight of the entire molten steel.

[0083] Meanwhile, if a casting speed is too low, solidification is completed before soft reduction so that a ratio of a liquid phase to a solid phase is too low to obtain the segregation-removing effect by soft reduction. On the contrary, if the casting speed is too high, a ratio of a liquid phase to a solid phase becomes too high, resulting in segregation caused by solidification shrinkage. Therefore, there is a need to control the casting speed such that the rolling reduction is 60% at a solidification fraction of 0.6 or more.

[0084] An amount of a coolant is adjusted appropriately such that solidification may be completed until the soft reduction is completed. A Mold Electro Magnetic Stirrer (Mold-EMS) and a Strand-EMS may be set according to conditions for conventional springs or arbitrarily set depending on equipment.

[0085] Meanwhile, unlike common wire rods for springs, spring steels for nitriding include a lot of highly alloying elements, and it is necessary to control carbonitrides therein. Therefore, according to an embodiment of the present disclosure, the internal carbonitride may be minimized by heating the prepared bloom at a temperature of 1,200°C or above and rolling the heated blood to a billet.

[0086] Subsequently, the billet may be heat-treated at a temperature of 1,030°C or above and rolled at a temperature of 1,000°C or below to prepare a wire rod.

[0087] If the heat treatment temperature for the billet is below 1030°C, the component V in the material does not sufficiently melt failing to form a solid solution of the carbide, thereby causing a problem of deterioration in softening resistance in a final product. The rolling of the billet to a wire rod may be performed at a temperature of 1000°C or below to perform the coiling at a temperature of 900°C or below.

[0088] Subsequently, the rolled wire rod may be coiled at a temperature of 800 to 900°C.

[0089] As a difference between the rolling temperature to prepare the wire rod and the coiling temperature increases, severe F decarburization may be caused by local supercooling. In consideration thereof, the process of coiling the rolled wire rod may be performed at a temperature of 800 to 900°C.

[0090] Then, the coiled wire rod may be cooled at a rate of 0.5 to 2°C/s.

[0091] Unlike common wire rods for springs, steels for spring for nitriding include a lot of highly alloying elements, and thus it is necessary to inhibit formation of a low-temperature structure. If the coiled wire rod is cooled at a rate less than 0.5°C/s, decarburization may occur. On the contrary, if the cooling speed exceeds 2°C/s, a material may break by a low-temperature structure.

[0092] Hereinafter, a steel wire for a spring with improved strength and fatigue limit according to an embodiment of the present disclosure will be described.

[0093] A steel wire for a spring with improved strength and fatigue limit according to an embodiment of the present disclosure may include, in percent by weight (wt%), 0.6 to 0.7% of C, 2.0 to 2.5% of Si, 0.2 to 0.7% of Mn, 0.9 to 1.5% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.01% or less of N, 0.25% or less of Mo, 0.25% or less of W, 0.05% to 0.2% of V, 0.05% or less of Nb, and the balance of Fe and unavoidable impurities.

[0094] In addition, the steel wire for a spring with improved strength and fatigue limit according to an embodiment of the present disclosure may satisfy $Mn+Cr \leq 1.8\%$.

[0095] In addition, the steel wire for a spring with improved strength and fatigue limit according to an embodiment of the present disclosure may satisfy $0.05\ at\% \leq Mo+W \leq 0.15\ at\%$.

[0096] Reasons for numerical limitations on the contents of alloying elements are as described above.

[0097] In addition, the steel wire for a spring with improved strength and fatigue limit according to an embodiment of the present disclosure may include, in area fraction, 85% or more of a tempered martensite structure and the balance of an austenite structure.

[0098] In addition, the steel wire for a spring with improved strength and fatigue limit according to an embodiment of the present disclosure may have a prior austenite average grain size of 15 μm or less.

[0099] In addition, in the steel wire for a spring with improved strength and fatigue limit according to an embodiment of the present disclosure, a proportion (wt%) of an area satisfying one or more of C > 0.85%, Si > 3.0%, Mn > 0.8%, and Cr > 2.0% may be 10% or less within an area of 1 mm^2 of a central region of a cross-section perpendicular to a lengthwise direction.

[0100] If the above-described proportion (wt%) of the area exceeds 10%, deterioration of quality of a material such as formation of a low-temperature structure due to central segregation may be caused, and deterioration of workability may be caused thereby increasing a frequency of breakage while processing a spring. In addition, if the above-described proportion (wt%) of the area exceeds 10%, the carbide effect may decrease due to concentration of carbide forming elements at the center.

[0101] In addition, in the steel wire for a spring with improved strength and fatigue limit according to an embodiment of the present disclosure, the number of carbonitrides having a maximum diameter of 15 μm or more distributed in a cross-section parallel to the lengthwise direction within a surface depth of 1 mm may be less than 2 per cm^2.

[0102] In the case where a carbonitride having a diameter of 15 μm or more is present on the surface of the steel wire, fatigue breakage may occur in the material. Therefore, it may be preferable to control the number of carbonitrides having a maximum diameter of 15 μm or more to be less than 2 per cm^2 in a cross-section parallel to the lengthwise direction within a surface depth of 1 mm.

[0103] In addition, in the steel wire for a spring with improved strength and fatigue limit according to an embodiment of the present disclosure, the number of carbides within an area of 100 μm^2 may be from 10 to 50, the maximum diameter of the carbides may be from 5 to 50 nm, and the content of V or Nb may be 10 at% or more.

[0104] Once a carbide including V or Nb grows over 10 nm, other carbide-forming elements such as Cr and Mo as well as V are included therein, and thus it is necessary to appropriately distribute carbide-forming elements used for inhibiting the growth of the prior austenite grains and carbide-forming elements used for precipitation hardening.

[0105] If the number of carbides having a maximum diameter of 5 to 50 nm is less than 10, it is difficult to control the prior austenite grain size. On the contrary, if the number of carbides having a maximum diameter of 5 to 50 nm is greater than 50, the carbides with 5 nm or less used for precipitation hardening decreases, thereby decreasing a tensile strength of the steel wire.

[0106] In addition, the steel wire for a spring with improved strength and fatigue limit according to an embodiment of the present disclosure may have a tensile strength of 2,100 MPa or more and a reduction of area (RA) of 45% or more.

[0107] Hereinafter, a method for manufacturing a steel wire for a spring with improved strength and fatigue limit according to an embodiment of the present disclosure will be described.

[0108] A method for manufacturing a steel wire for a spring according to an embodiment of the present disclosure includes: performing LA heat treatment on the wire rod according to an embodiment of the present disclosure; performing LP heat treatment; and drawing the wire rod to prepare a steel wire; and performing QT heat treatment on the steel wire.

[0109] First, the wire rod according to an embodiment of the present disclosure may be subjected to a low temperature annealing (LA) at a temperature of 650 to 750°C.

[0110] Although not limited thereto, as a processing time of the LA heat treatment increases, the carbide coarsens making it difficult to control the carbide during a subsequent process, and thus the LA heat treatment may be performed within 2 hours. By the LA heat treatment, the strength of the wire rod may decrease to 1,200 MPa or less. If required, the LA heat treatment process may be omitted.

[0111] Then, the LA heat-treated wire rod is acid-pickled and lead patenting (LP) heat treatment may be performed.

[0112] The LP heat treatment may include a primary austenizing process of heating to a temperature of 950 to 1 100°C within 3 minutes and maintaining for 3 minutes or less; and a process of passing the primarily austenized wire rod through a Pb bath at a temperature of 650 to 700°C within 3 minutes.

[0113] By performing the austenizing process of heating to a temperature of 950 to 1100°C within 3 minutes and maintaining for 3 minutes or less, an austenite structure may be obtained and the carbide coarsened in the LA process may form a solid solution again.

[0114] Subsequently, the primarily austenized wire rod may be isothermally transformed via rapid cooling by passing through a Pb bath at a temperature of 650 to 750°C within 3 minutes, and a pearlite structure may be obtained. If the Pb bath temperature is below 650°C, a low-temperature structure may be formed. On the contrary, if the Pb bath temperature is above 750°C, the carbide coarsens and strength may decrease.

[0115] Subsequently, LP heat-treated wire rod may be drawn to prepare a steel wire. In this regard, the prepared steel wire may have a wire diameter of 5 mm. The LP heat treatment may be performed again to control the wire diameter of the steel wire to 2 mm or less.

[0116] Subsequently, the prepared steel wire may be subjected to QT heat treatment process to obtain a tempered martensite structure.

[0117] According to an embodiment of the present disclosure, the QT heat treatment may include a secondary austenizing process of heating to a temperature of 900 to 1000°C within 3 minutes and maintaining for 3 minutes or less; and a primary oil quenching process performed at 70°C or below; a tempering process of heating to a temperature of 450 to 550°C within 3 minutes and maintaining for 3 minutes or less; and a secondary oil quenching process performed at 70°C or below.

[0118] In the QT heat treatment, the austenizing temperature may be from 900 to 1000°C such that the fine carbides precipitated during the LP heat treatment are maintained. Although not limited thereto, the austenizing process may be performed for 6 minutes or less in the QT heat treatment.

[0119] If the tempering temperature is below 450°C in the QT heat treatment, the nitriding temperature is lowered, formation of additional carbides cannot be induced, and toughness may deteriorate. On the contrary, if the tempering temperature exceeds 550°C in the QT heat treatment, a sufficient strength cannot be obtained.

[0120] Hereinafter, a spring with improved strength and fatigue limit according to an embodiment of the present disclosure will be described.

[0121] A spring with improved strength and fatigue limit according to an embodiment of the present disclosure includes, in percent by weight (wt%), 0.6 to 0.7% of C, 2.0 to 2.5% of Si, 0.2 to 0.7% of Mn, 0.9 to 1.5% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.01% or less of N, 0.25% or less of Mo, 0.25% or less of W, 0.05% to 0.2% of V, 0.05% or less of Nb, and the balance of Fe and unavoidable impurities, satisfies Mn+Cr≤1.8%, and satisfies 0.05 at%≤Mo+W≤0.15 at%.

[0122] Reasons for numerical limitations on the contents of alloying elements are as described above.

[0123] In addition, in the spring according to an embodiment of the present disclosure, a fatigue limit increases by 10% or more after nitriding. In this regard, the fatigue limit refers to a limit withstanding repeated loads more than 10 million times during a fatigue test after designing a spring.

[0124] In addition, the spring according to an embodiment of the present disclosure may have a fatigue limit of 700 MPa or more which withstands repeated stress more than 10 million times.

[0125] In addition, in the spring according to an embodiment of the present disclosure, a strength change before and after nitriding is 15% or less, and a nitriding temperature may be 430°C or above.

[0126] Hereinafter, a method for manufacturing a spring with improved strength and fatigue limit according to an embodiment of the present disclosure will be described.

[0127] A method for manufacturing a spring with improved strength and fatigue limit according to an embodiment of the present disclosure includes: cold forming the steel wire according to an embodiment of the present disclosure in a spring form; performing stress-relieving heat treatment on the formed spring; and nitriding the resultant.

[0128] The fatigue limit of the steel wire according to an embodiment of the present disclosure may be improved by performing nitriding before shot peening in the spring-manufacturing process. In this regard, if the nitriding temperature is too low, nitrogen cannot appropriately penetrate into the surface. If the nitriding temperature is too high, hardness of the central region of the material decreases and a desired strength of the material cannot be obtained. In consideration thereof, the nitriding process may be performed at a temperature of 420 to 450°C for 10 hours or more.

[0129] 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

[0130] Steel materials including various compositions of alloying elements shown in Table 1 below were continuously cast with a total soft reduction of 10 to 25 mm to prepare blooms. The prepared blooms were subjected to heat treatment at a temperature of 1,200°C for homogenization and heat treatment at a temperature of 1050°C, and then hot rolled to a final wire diameter of 6.5 mm while cooling to 850°C to prepare wire rods having a final wire diameter of 6.5 mm. Then, the hot-rolled wire rods were coiled at a temperature of 800 to 900°C and cooled at a rate of 1°C/s.

Table 1

	Alloying element (wt%)										
	C	Si	Mn	Cr	P	S	Mo	V	Al	Nb	W
Example 1	0.63	2.2	0.3	1.2	0.009	0.005	0.2	0.15	<0.003	0.02	
Example 2	0.63	2.2	0.3	1.2	0.011	0.005	0.15	0.15	<0.003		0.1
Comparative Example 1	0.63	2.2	0.3	1.2	0.009	0.005	0.2	0.15	<0.003	0.02	
Comparative Example 2	0.63	2.2	0.3	1.2	0.011	0.005	0.15	0.02	<0.003		0.1
Comparative Example 3	0.63	2.2	0.3	1.2	0.009	0.005	0.2	0.15	<0.003	0.02	0.2
Comparative Example 4	0.63	2.2	0.3	1.2	0.009	0.005	0.2	0.15	<0.003	0.02	

[0131] Table 2 below shows at% contents of W+Mo and total soft reduction of the examples and comparative examples. The segregation areas of Table 2 below were derived by analyzing 1 mm^2 of a central region of a cross-section perpendicular to a lengthwise direction of the prepared wire rod. The 'C segregation area' of Table 2 refers to a proportion of an area satisfying C > 0.85 wt% within an area of 1 mm^2 of a central region of a cross-section perpendicular to a lengthwise direction. The 'Si segregation area' refers to a proportion of an area satisfying Si > 3.0 wt% within an area of 1 mm^2 of a central region of a cross-section perpendicular to a lengthwise direction. The 'Mn segregation area' refers to a proportion of an area satisfying Mn > 0.8 wt% within an area of 1 mm^2 of a central region of a cross-section perpendicular to a lengthwise direction. The 'Cr segregation area' refers to a proportion of an area satisfying Cr > 2.0

wt% within an area of 1 mm^2 of a central region of a cross-section perpendicular to a lengthwise direction. The segregation area was measured by using an Electron Probe X-ray Micro Analyzer, EPMA (Model No. E MPA-1600).

Table 2

	W+Mo (at%)	Total soft reductio n (mm)	C segregat ion area (%)	Si segregat ion area (%)	Mn segregat ion area (%)	Cr segregat ion area (%)	Sum of C, Si, Mn, and Cr segregatio n areas (%)
Example 1	0.11	25 mm	<1%	2.5	<1%	2.5	<7%
Example 2	0.08	25 mm	<1%	4.3	<1%	2.3	<8.6%
Comparative Example 1	0.11	10 mm	5.5	11.2	3.1%	10.2	30%
Comparative Example 2	0.08	25 mm	<1%	4.5	<1%	2.2	<8.7%
Comparative Example 3	0.17	25 mm	<1%	3.2	<1%	3.4	<8.6%
Comparative Example 4	0.11	25 mm	<1%	4.2	<1%	2.4	<8.6%

[0132] Referring to Table 2, because Examples 1 and 2 satisfy the composition of alloying elements and the total soft reduction suggested by the present disclosure, the sum of C, Si, Mn, and Cr segregation areas was not more than 10%. On the contrary, because Comparative Example 1 had the total soft reduction was 10 mm which is less than 20 mm, the sum of C, Si, Mn, Cr segregation areas was 30%.

[0133] Table 3 below shows tensile strength, reduction of area (RA), central low-temperature structure, prior austenite average grain size, pearlite structure, and the number of carbonitrides of the prepared wire rods. The prior austenite average grain size, the pearlite structure, and the number of carbonitrides were measured by using a scanning electron microscope (SEM) (Model No. JEOL, JSM-6610LV).

[0134] The 'O' of Table 3 indicates a case in which an area fraction of the low-temperature structure exceeded 20%, and the 'X' indicates a case in which an area fraction of the low-temperature structure is not more than 20%.

[0135] 8 samples were prepared by cutting a 3 m-long wire rod into 8 pieces. The pearlite structure of Table 3 below refers to the number of samples in which an area fraction of the pearlite structure was 80% or more in a microstructure of a cross-section perpendicular to the lengthwise direction of each sample.

[0136] 10 samples were prepared by cutting a 10 cm-long wire rod into 10 pieces each having a length of 1 cm. The number of carbonitrides of Table 3 below refers to the number of carbonitrides having a maximum diameter of 15 μm or more measured in a microstructure of a cross-section of the sample parallel to a lengthwise direction within a surface depth of 1 mm.

Table 3

	Tensile strength (MPa)	Reductio n of area of wire rod (%)	Central low-temperatur e structure	Prior austenite average grain size (μm)	Pearlite structure	No. of carbonitri des
Example 1	1221	42	X	14	7/8	0
Example 2	1231	35	X	18	8/8	0
Comparative Example 1	1455	25	O	20	5/8	2
Comparative Example 2	1253	35	X	24	7/8	0
Comparative Example 3	1510	10	O	15	2/8	0
Comparative Example 4	1233	42	X	16	8/8	0

[0137] Referring to Table 3, in Examples 1 and 2, a low-temperature structure was not formed in central areas, and the prior austenite average grain size was not more than 20 μm. In addition, among 8 samples, 6 or more samples exhibited 80% or more of the pearlite structure according to Examples 1 and 2, and the tensile strength was not more than 1400 MPa indicating excellent workability. Also, a carbonitride was not formed on the surfaces in Examples 1 and 2.

[0138] On the contrary, according to Comparative Example 1, the tensile strength exceeded 1400 MPa, the reduction of area less than 35% exhibited inferior workability, and the low-temperature structure was formed in the central area. In addition, according to Comparative Example 1, only 5 samples included 80% or more of the pearlite structure among the 8 samples, and 80% of more of the pearlite structure was not uniformly formed.

[0139] In Comparative Example 2, referring to the alloying elements of Table 1, because the V content was less than 0.15%, the prior austenite average grain size was 24 μm exceeding 20 μm indicating coarsening of grains.

[0140] In Comparative Example 3, because the tensile strength was 1510 MPa and the reduction of area was only 10%, workability was inferior and a low-temperature structure was formed in the central area. In addition, in Comparative Example 3, only 2 samples includes 80% or more of the pearlite structure among the 8 sample, indicating that the pearlite structure was not sufficiently formed.

[0141] Subsequently, the samples of the examples and comparative examples were subjected to LA heat treatment at 720°C for 2 hours and acid pickling, and then LP heat treatment was performed. The LP heat treatment was performed by heating to a primary austenizing temperature within 3 minutes, and then proceeded under conditions shown in Table 4 below. In addition, Table 4 showed pearlite transformation time of LP heat treatment according to the examples and the comparative examples. The pearlite transformation time was measured by deriving a time-temperature-transformation (TTT) curve via a dilatometry experiment.

[Table 4]

	LP heat treatment				
	Primary austenizing		Pb bath		Pearlite transformation time during LP heat treatment (sec)
	Temperatur e (°C)	Maintaining time (min)	Temperatur e (°C)	Passing time (min)	
Example 1	1000	3	675	2	110
Example 2	1000	3	675	2	105
Comparative Example 1	1000	3	675	2	110
Comparative Example 2	1000	3	675	2	112
Comparative Example 3	1000	3	675	2	130
Comparative Example 4	930	3	690	2	110

[0142] The pearlite transformation time of Examples 1 and 2 was 110 seconds and 105 seconds, respectively less than 130 seconds, indicating excellent productivity. On the contrary, the pearlite transformation time of Comparative Example 3 was 130 seconds indicating inferior productivity to the extent that field production is difficult.

[0143] Subsequently, the LP heat-treated materials of the examples and comparative examples were drawn to prepare steel wires having a wire diameter of 3 mm. The prepared steel wires were subjected to a secondary austenizing process and a primary quenching process, and then tempered and subjected to a secondary quenching process to obtain QT steel wires. The steel wires were heated to a secondary austenizing temperature within 3 minutes, and the primary and secondary quenching processes were performed in an oil at 60°C. The remaining process was performed under conditions of Table 5 below.

[Table 5]

	QT heat treatment			
	Secondary austenizing	Tempering		
	Temperature (°C)	Maintaining time (min)	Temperature (°C)	Maintaining time (min)
Example 1	930	2	470	2
Example 2	930	2	470	2
Comparative Example 1	930	2	470	2
Comparative Example 2	930	2	470	2
Comparative Example 3	930	2	470	2
Comparative Example 4	930	2	470	2

[0144] Table 6 below shows tensile strength, reduction of area (RA), and the number of carbides of the prepared QT steel wires. In this regard, the number of carbides refers to the number of carbides having a maximum diameter of 5 to 50 nm and including the content of V or Nb is 10 at% or more in an area of 100 μm^2. The number of carbides refers to an average of 8 values measured from 8 positions in an area of 100 μm^2 of the surface of the wire rod by using a transmission electron microscope (TEM) of FEI Tecnai OSIRIS.

[Table 6]

	Tensile strength of QT steel wire (MPa)	Reduction of area of QT steel wire (%)	No. of carbides
Example 1	2242	51	31
Example 2	2232	49	23
Comparative Example 1	2232	32	65
Comparative Example 2	2180	44	2
Comparative Example 3	2352	44	24
Comparative Example 4	2120	46	61

[0145] Referring to Table 6, Examples 1 and 2 exhibited 2200 MPa or more of excellent tensile strengths and 45% or more of reduction of area. In addition, the number of carbides of Examples 1 and 2 was from 10 to 50.

[0146] On the contrary, the reduction of area of Comparative Example 1 was only 32% and the number of carbides exceeded 50. According to Comparative Example 2, an inferior tensile strength not more than 2200 MPa was obtained, and the number of carbides was less than 10 causing a problem of difficulties in controlling the prior austenite average grain size. Comparative Example 4 exhibited an inferior tensile strength of 2200 MPa or less and the number of carbides exceeded 50.

[0147] Subsequently, the QT steel wire was cold formed in a spring shape and the formed spring was heat treated and nitrided at a temperature of 420 to 450°C.

[0148] Table 7 below shows whether the spring breaks while forming the spring, fatigue limit values, and fatigue limit after nitriding.

[0149] The fatigue limits before and after nitriding were measured under the conditions of a stress ratio R (tensile capacity/compression capacity) of -1 and a test speed of 30 to 60 Hz.

[0150] In table 7 below, 'X' indicates that breakage did not occur while forming the spring, and 'O' indicates that breakage occurred while forming the spring.

[Table 7]

	Breakage	Fatigue limit before nitriding (MPa)	Fatigue limit after nitriding (MPa)
Example 1	X	700	780
Example 2	X	710	780
Comparative Example 1	O	680	750
Comparative Example 2	O	650	700
Comparative Example 3	X	700	770
Comparative Example 4	X	660	710

[0151] The samples of Examples 1 and 2 did not break due to excellent workability and had excellent fatigue limits over 650 MPa before nitriding. In addition, the samples of Examples 1 and 2 had fatigue limits over 750 MPa after nitriding. Since the fatigue limit after nitriding was higher than that before nitriding by 10% or more, excellent nitriding properties were obtained.

[0152] On the contrary, Comparative Examples 1 and 2 exhibited breakage due to inferior workability, and the fatigue limit after nitriding increased by less than 10% compared to that before nitriding.

[0153] Although the spring of Comparative Example 4 did not break during processing, the fatigue limit after nitriding could not be increased by 10% or more compared to that before nitriding, indicating inferior nitriding properties.

[0154] According to the disclosed embodiments, by optimizing the composition of alloying elements and conditions of the manufacturing process, excellent tensile strength and reduction of area may be obtained and also nitriding properties and fatigue limit may be improved, and thus the spring may be applicable as a material of transmissions and engine valves of vehicles.

[Industrial Applicability]

[0155] According to an embodiment of the present disclosure, a wire rod and a steel wire for a spring and a spring with improved strength and fatigue limit and a method for manufacturing the same may be provided.

Claims

1. A wire rod for a spring with improved strength and fatigue limit, the wire rod comprising, in percent by weight (wt%), 0.6 to 0.7% of C, 2.0 to 2.5% of Si, 0.2 to 0.7% of Mn, 0.9 to 1.5% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.01% or less of N, 0.25% or less of Mo, 0.25% or less of W, 0.05% to 0.2% of V, 0.05% or less of Nb, and the balance of Fe and unavoidable impurities,

   wherein Mn+Cr≤1.8% is satisfied,
   0.05 at%≤Mo+W≤0.15 at% is satisfied,
   a proportion (wt%) of an area satisfying one or more of C > 0.85%, Si > 3.0%, Mn > 0.8%, and Cr > 2.0% is 10% or less within an area of 1 mm^2 of a central region of a cross-section perpendicular to a lengthwise direction.

2. The wire rod according to claim 1, wherein the wire rod comprises, in an area fraction, 80% or more of a pearlite structure and the balance of a bainite structure or a martensite structure.

3. The wire rod according to claim 1, wherein a prior austenite average grain size is 20 μm or less.

4. The wire rod according to claim 1, wherein the number of a carbonitride having a maximum diameter of 15 μm or more distributed in a cross-section parallel to a lengthwise direction within a surface depth of 1 mm is less than 2 per cm^2.

5. The wire rod according to claim 1, wherein a tensile strength is 1,400 MPa or less, and a reduction of area is 35% or more.

6. A method for manufacturing a wire rod for a spring with improved strength and fatigue limit, the method comprising:

preparing a bloom by continuously casting a molten steel including, in percent by weight (wt%), 0.6 to 0.7% of C, 2.0 to 2.5% of Si, 0.2 to 0.7% of Mn, 0.9 to 1.5% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.01% or less of N, 0.25% or less of Mo, 0.25% or less of W, 0.05% to 0.2% of V, 0.05% or less of Nb, and the balance of Fe and unavoidable impurities;
heating the bloom at a temperature of 1,200°C or above and rolling the bloom to prepare a billet;
heating the billet at a temperature of 1,030°C or above and rolling the billet at a temperature of 1,000°C below to prepare a wire rod;
coiling the rolled wire rod at a temperature of 800 to 900°C; and
cooling the coiled wire rod at a seed of 0.5 to 2°C/sec.

7. The method according to claim 6, wherein the continuously casting process comprises performing soft reduction with a total rolling reduction 20 mm or more.

8. The method according to claim 7, wherein the soft reduction is performed to allow each roll to roll by reducing 4 mm or less and have a cumulative rolling reduction of 60% or more at a solidification fraction of 0.6 or more.

9. A steel wire for a spring with improved strength and fatigue limit, the steel wire comprising, in percent by weight (wt%), 0.6 to 0.7% of C, 2.0 to 2.5% of Si, 0.2 to 0.7% of Mn, 0.9 to 1.5% of Cr, 0.015% or less of P, 0.01% or less of S, 0.01% or less of Al, 0.01% or less of N, 0.25% or less of Mo, 0.25% or less of W, 0.05% to 0.2% of V, 0.05% or less of Nb, and the balance of Fe and unavoidable impurities,

wherein Mn+Cr≤1.8% is satisfied,
0.05 at%≤Mo+W≤0.15 at% is satisfied, and
the steel wire comprises, in an area fraction, 85% or more of a tempered martensite structure and the balance of an austenite structure.

10. The steel wire according to claim 9, wherein a prior austenite average grain size is 15 μm or less.

11. The steel wire according to claim 9, wherein the number of a carbonitride having a maximum diameter of 15 μm or more distributed in a cross-section parallel to the lengthwise direction within a surface depth of 1 mm is less than 2 per cm^2.

12. The steel wire according to claim 9, wherein the number of carbides in an area of 100 μm^2 is from 10 to 50, the maximum diameter of the carbide is from 5 to 50 nm, and a content of V or Nb is 10 at% or more.

13. The steel wire according to claim 9, wherein a tensile strength is 2,100 MPa or more, and a reduction of area is 45% or more.

14. A method for manufacturing a steel wire for a spring with improved strength and fatigue limit, the method comprising:

performing LA heat treatment on the wire rod according to any one of claims 1 to 5;
drawing the LP heat-treated wire rod to prepare a steel wire; and
performing QT heat treatment on the steel wire,
wherein the LP heat treatment comprises:

a primary austenizing process of heating to a temperature of 950 to 1100°C within 3 minutes and maintaining for 3 minutes or less; and
a process of passing the primarily austenized wire rod through a Pb bath at a temperature of 650 to 700°C within 3 minutes.

15. The method according to claim 14, wherein, in the LP heat treatment, a pearlite transformation completion time is less than 130 seconds.

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/34(2006.01)i; **C22C 38/22**(2006.01)i; **C22C 38/24**(2006.01)i; **C22C 38/26**(2006.01)i; **C22C 38/00**(2006.01)i; **C21D 8/02**(2006.01)i; **C21D 1/18**(2006.01)i; **C21D 9/54**(2006.01)i; **B22D 11/00**(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)

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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: 강도(strength), 피로한도(fatigue limit), 스프링(spring), 선재(wire rod), 강선(steel wire), 압연(rolling), 권취(winding), 냉각(cooling), 납 패턴팅(lead patenting), 퀜칭(quenching), 템퍼링(tempering)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	KR 10-2012-0040728 A (NIPPON STEEL CORPORATION) 27 April 2012 (2012-04-27) See paragraph [0244]; and claims 1-2 and 8.	6
A		1-5,7-15
Y	JP 2009-068030 A (KOBE STEEL LTD.) 02 April 2009 (2009-04-02) See paragraph [0002]; and claim 7.	6
A	KR 10-2021-0036916 A (BAOSHAN IRON & STEEL CO., LTD.) 05 April 2021 (2021-04-05) See paragraphs [0037]-[0038].	1-15
A	KR 10-2013-0026135 A (POSCO) 13 March 2013 (2013-03-13) See claim 2.	1-15
A	KR 10-2011-0048744 A (POSCO) 12 May 2011 (2011-05-12) See paragraphs [0009]-[0018].	1-15

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

* Special categories of cited documents:
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- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 August 2022	**29 August 2022**
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
Information on patent family members

International application No.
PCT/KR2022/007483

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