



(11)

EP 4 509 631 A1

(12)

EUROPEAN PATENT APPLICATION
published in accordance with Art. 153(4) EPC

(43) Date of publication:
19.02.2025 Bulletin 2025/08

(21) Application number: **23816361.2**

(22) Date of filing: **31.05.2023**

(51) International Patent Classification (IPC):
C22C 38/18 ^(2006.01) **C22C 38/00** ^(2006.01)
B21B 1/16 ^(2006.01) **C21D 8/06** ^(2006.01)
C21D 9/52 ^(2006.01)

(52) Cooperative Patent Classification (CPC):
B21B 1/16; C21D 8/06; C21D 9/52; C22C 38/00;
C22C 38/18

(86) International application number:
PCT/KR2023/007440

(87) International publication number:
WO 2023/234700 (07.12.2023 Gazette 2023/49)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL
NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
KH MA MD TN

(30) Priority: **31.05.2022 KR 20220066879**

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(54) **NON-QUENCHED AND TEMPERED STEEL WIRE ROD WITH IMPROVED MACHINABILITY AND TOUGHNESS, AND METHOD FOR MANUFACTURING SAME**

(57) Provided are a non-quenched and tempered steel wire rod with improved machinability and impact toughness and a method for manufacturing the same. The non-quenched and tempered steel wire rod according to the present disclosure includes, in percent by weight (wt%), 0.3% to 0.5% of C, 0.4% to 0.9% of Si, 0.5% to 1.2% of Mn, 0.02% or less of P, 0.01% to 0.05% of S, 0.015% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.007% to 0.02% of N, and the remainder including Fe and inevitable impurities, has a microstructure in which an average thickness of the pearlite layer in a L cross-section, which is parallel to a rolling direction, is 30 μm or less, an average grain size of ferrite is 20 μm or less, and Relational Expressions 1 to 5 are satisfied.

$$\text{[Relational Expression 1]} \quad 20 \leq \text{Mn/S} \leq 70$$

$$\text{[Relational Expression 2]} \quad 1.4 \leq \text{Al/N} \leq 7$$

$$\text{[Relational Expression 3]} \quad 0.7 \leq \text{Mn} + \text{Cr} \leq 1.4$$

$$\text{[Relational Expression 4]} \quad 0.2 \leq \text{C/Mn} \leq 0.7$$

$$\text{[Relational Expression 5]} \quad 0 \leq \text{Mn}_c/\text{Mn}_f \leq 3.$$

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Description

[Technical Field]

[0001] The present disclosure relates to a non-quenched and tempered steel wire rod with excellent machinability and impact toughness and a method for manufacturing the same, and more particularly, to a non-quenched and tempered steel wire rod suitable for use as a material for automobiles or mechanical parts and a method for manufacturing the same.

[Background Art]

[0002] Unlike quenched and tempered steels, which obtain certain levels of strength and toughness by quenching and tempering (QT) heat treatment, the QT heat treatment process is omitted in non-quenched and tempered steels. Therefore, non-quenched and tempered steels are not only economically advantageous by reducing heat treatment costs, simplifying processes to shorten delivery time, and improving productivity, but also eco-friendly by reducing CO₂ that is generated by operating a furnace during heat treatment. At the beginning of development, non-quenched and tempered steels were applied only to parts that do not require high toughness due to relatively inferior toughness thereof to that of quenched and tempered steels. However, with a recent increase in the demand for environmental feasibility and cost reduction, demand for improving toughness of non-quenched and tempered steels is increasing. In addition, because a cutting process is often conducted to obtain final shapes of parts, machinability is also required. In general, a large amount of MnS is generated by adding S to improve machinability, thereby causing a problem of reduction in toughness of products.

[Disclosure]

[Technical Problem]

[0003] An aspect of the present disclosure provides a non-quenched and tempered steel wire rod with improved machinability and impact toughness by improving toughness inferior to that of conventional quenched and tempered steels and by adding high contents of S and N without additional heat treatment, and a method for manufacturing the same.

[Technical Solution]

[0004] A non-quenched and tempered steel wire rod with improved machinability and impact toughness according to an embodiment of the present disclosure includes, in percent by weight (wt%), 0.3% to 0.5% of C, 0.4% to 0.9% of Si, 0.5% to 1.2% of Mn, 0.02% or less of P, 0.01% to 0.05% of S, 0.015% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.007% to 0.02% of N, and the remainder including Fe and inevitable impurities, wherein a microstructure includes ferrite and pearlite, and an average thickness of the pearlite layer in a L cross-section, which is a cross-section parallel to a rolling direction, is 30 μm or less.

[0005] According to an embodiment of the present disclosure, in the non-quenched and tempered steel wire rod, an average grain size of ferrite in a C cross-section, which is a cross-section perpendicular to the rolling direction, may be 20 μm or less.

[0006] According to an embodiment of the present disclosure, the non-quenched and tempered steel wire rod satisfies Relational Expression 1 below.

$$\text{[Relational Expression 1]} \quad 20 \leq \text{Mn/S} \leq 70$$

[0007] According to an embodiment of the present disclosure, the non-quenched and tempered steel wire rod satisfies Relational Expression 2 below.

$$\text{[Relational Expression 2]} \quad 1.4 \leq \text{Al/N} \leq 7$$

[0008] According to an embodiment of the present disclosure, the non-quenched and tempered steel wire rod satisfies Relational Expression 3 below.

$$\text{[Relational Expression 3]} \quad 0.7 \leq \text{Mn} + \text{Cr} \leq 1.4$$

[0009] According to an embodiment of the present disclosure, the non-quenched and tempered steel wire rod satisfies Relational Expression 4 below.

$$[\text{Relational Expression 4}] \quad 0.2 \leq C/Mn \leq 0.7$$

[0010] According to an embodiment of the present disclosure, the non-quenched and tempered steel wire rod satisfies Relational Expression 5 below.

$$[\text{Relational Expression 5}] \quad 0 \leq Mn_c/Mn_f \leq 3$$

(wherein Mn_c represents an average content (at%) of Mn contained in cementite in pearlite, and Mn_f represents an average content (at%) of Mn contained in ferrite in pearlite.)

[0011] According to an embodiment of the present disclosure, the non-quenched and tempered steel wire rod may have a tensile strength of 700 MPa or more and a yield strength of 350 to 500 MPa. In addition, a yield ratio (yield strength/tensile strength) may be in a range of 0.45 to 0.65, a room-temperature impact toughness may be 60 J/cm² or more, and a product of the tensile strength and the impact toughness may be 45000 MPa·J/cm² or more.

[0012] A method for manufacturing a non-quenched and tempered steel wire rod with improved machinability and impact toughness according to an embodiment of the present disclosure includes: reheating a steel piece including, in percent by weight (wt%), 0.3% to 0.5% of C, 0.4% to 0.9% of Si, 0.5% to 1.2% of Mn, 0.02% or less of P, 0.01% to 0.05% of S, 0.015% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.007% to 0.02% of N, and the remainder including Fe and inevitable impurities in a temperature range of 950°C to 1100°C; finish rolling the reheated steel piece into a steel wire rod at a temperature of 750°C to 850°C; and winding and cooling the steel wire rod,

wherein the cooling performed after the winding includes: a first cooling process performed at an average cooling rate of 5°C/s to 100°C/s from the finish rolling temperature to a winding temperature; a second cooling process performed after the first cooling process at an average cooling rate of 2°C/s to 5°C/s from the winding temperature to 700°C; and a third cooling process performed after the second cooling process at an average cooling rate of 0.1°C/s to 2°C/s from 700°C to 450°C, wherein a microstructure of the steel wire rod includes ferrite and pearlite, and an average thickness of the pearlite layer in a L cross-section, which is a cross-section parallel to a rolling direction, is 30 μm or less.

[Advantageous Effects]

[0013] In the non-quenched and tempered steel wire rod with improved machinability and impact toughness according to an embodiment of the present disclosure, Al combines with N to form AlN nitrides that inhibit the growth of grain boundaries during heating, thereby decreasing the thickness of the pearlite layer and refine grains of ferrite to improve impact toughness. In addition, machinability may be improved while minimizing deterioration of impact toughness by refining MnS grains by controlling the Mn/S ratio. Therefore, the steel wire rod may be applied to materials for automobiles or mechanical parts that require both machinability and impact toughness even when heat treatment is omitted.

[Best Mode]

[0014] A non-quenched and tempered steel wire rod with improved machinability and impact toughness according to an embodiment of the present disclosure includes, in percent by weight (wt%), 0.3% to 0.5% of C, 0.4% to 0.9% of Si, 0.5% to 1.2% of Mn, 0.02% or less of P, 0.01% to 0.05% of S, 0.015% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.007% to 0.02% of N, and the remainder including Fe and inevitable impurities, wherein a microstructure includes ferrite and pearlite, and an average thickness of the pearlite layer in a L cross-section, which is a cross-section parallel to a rolling direction, is 30 μm or less.

[Modes of the Invention]

[0015] This specification does not describe all elements of the embodiments of the present disclosure and detailed descriptions on what are well known in the art or redundant descriptions on substantially the same configurations may be omitted. In addition, the term "include" an element does not preclude other elements but may further include another element, unless otherwise stated. As used herein, the singular forms are intended to include the plural forms as well, unless the context clearly indicates otherwise. Hereinafter, reasons for numerical limitations on the contents of alloying elements in the embodiment of the present disclosure will be described. Hereinafter, the present disclosure will be described in detail.

[0016] The present inventors have examined a method for providing a steel wire rod with machinability and impact toughness from various angles and have found that machinability and impact toughness may be obtained by appropriately controlling a composition of alloying elements and a microstructure of the steel wire rod without additional heat treatment, thereby completing the present disclosure.

[0017] A non-quenched and tempered steel wire rod with improved machinability and impact toughness according to an embodiment of the present disclosure includes, in percent by weight (wt%), 0.3% to 0.5% of C, 0.4% to 0.9% of Si, 0.5% to 1.2% of Mn, 0.02% or less of P, 0.01% to 0.05% of S, 0.015% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.007% to 0.02% of N, and the remainder including Fe and inevitable impurities, wherein a microstructure includes ferrite and pearlite, and an average thickness of the pearlite layer in a L cross-section, which is a cross-section parallel to a rolling direction, is 30 μ m or less. Hereinafter, the unit is wt% unless otherwise stated.

[0018] The content of C is 0.3% to 0.5%.

[0019] Carbon (C) is an element serving to improve strength of a steel wire rod. To obtain the above-described effect, it is preferable to include C in an amount of 0.3% or more. However, an excessive C content may deteriorate toughness and machinability, and thus the upper limit of the C content may be controlled to 0.5%.

[0020] The content of Si is 0.4% to 0.9%.

[0021] Silicon (Si), as an element effective as a deoxidizer, serves to improve strength. With a Si content less than 0.4%, the above-described effect cannot be obtained. With a Si content exceeding 0.9%, deformation resistance of a steel rapidly increases due to solid solution strengthening, and therefore, the upper limit of the Si content may be controlled to 0.9%.

[0022] The content of Mn is 0.5% to 1.2%.

[0023] Manganese (Mn) is an element effective as a deoxidizer and a desulfurizer. With a Mn content less than 0.5%, the above-described effect cannot be obtained. With a Mn content exceeding 1.2%, strength of the steel excessively increases to rapidly increase deformation resistance of the steel, resulting in deterioration of cold workability, and therefore, the upper limit of the Mn content may be controlled to 1.2%.

[0024] The content of P is 0.02% or less.

[0025] Phosphorus (P), as an impurity inevitably contained in steels, segregate into grain boundaries as a major causative element deterioration of toughness and reduction in delayed fracture resistance. Therefore, it is preferable to control the P content as low as possible. Theoretically, it is preferable to control the P content to 0% but P is inevitably included during a manufacturing process. Therefore, it is important to control the upper limit, and the upper limit of the P content may be controlled to 0.02% in the present disclosure.

[0026] The content of S is 0.01% to 0.05%.

[0027] Sulfur (S), as a major causative element of significant deterioration in ductility of a steel due to segregation into grain boundaries and deterioration in delayed fracture resistance and stress relaxation due to formation of an emulsion in a steel, is an impurity inevitably contained in the steel during a manufacturing process. However, as in the present disclosure, S may actively be used to improve machinability. Because S combines with Mn to form MnS that improves machinability, the S content is controlled within a range of 0.01% to 0.05% in the present disclosure in consideration of an S content effective for improvement of machinability without significantly impairing toughness of the steel.

[0028] The content of sol.Al is 0.015% to 0.05%.

[0029] The sol.Al is an element effective as a deoxidizer. The sol.Al may be contained in an amount of 0.015% to obtain the above-describe effect. However, with an Al content exceeding 0.05%, difficulties may arise during a manufacturing process due to Al oxides generated during a casting process. Therefore, the upper limit of the Al content may be controlled to 0.05% in the present disclosure.

[0030] The content of Cr is 0.1% to 0.3%.

[0031] Chromium (Cr) is an element serving to promote transformation of ferrite and pearlite during hot rolling. In addition, Cr does not increase the strength of the steel more than necessary, reduces an amount of solid solution of C by precipitating carbides, and contributes to reduction in dynamic deformation aging caused by solid solution of carbon. With a Cr content less than 0.1%, the above-described effects cannot be obtained, and with a C content exceeding 0.3%, strength of the steel excessively increases to rapidly increase deformation resistance of the steel, resulting in deterioration of cold workability. Therefore, the upper limit of the Cr content may be controlled to 0.3%.

[0032] The content of N is 0.007% to 0.02%.

[0033] N is an essential element for implementing an effect on improving impact toughness by decreasing grain sizes via formation of a nitride with Al. With a N content less than 0.007%, it is difficult to obtain a sufficient amount of the nitride, resulting in a decrease in production of AlN precipitates, failing to obtain toughness desired in the present disclosure. With a N content exceeding 0.02%, a solid solution of N, not present as a nitride, increases to deteriorate toughness and ductility of the steel wire rod. Therefore, the upper limit of the N content may be controlled to 0.02% in the present disclosure.

[0034] The remaining component of the non-quenched and tempered steel wire rod of the present disclosure is iron (Fe). However, the non-quenched and tempered steel wire rod may include other impurities incorporated during common industrial manufacturing processes of steels. The impurities are not specifically mentioned in the present disclosure, as they are known to any person skilled in the art of manufacturing.

[0035] The non-quenched and tempered steel wire rod according to an embodiment of the present disclosure includes ferrite and pearlite as microstructures, and an average thickness of the pearlite layer in the L cross-section, which is a cross-section parallel to a rolling direction, may be 30 μm or less. In the case where the thickness of pearlite exceeds 30 μm and a band of coarse pearlite is formed, a total interface between ferrite and pearlite decreases and an impact energy cannot be distributed, so that cracks easily propagate and impact toughness decreases.

[0036] In the non-quenched and tempered steel wire rod according to an embodiment of the present disclosure, an average grain size of ferrite in a C cross-section, which is a cross-section perpendicular to the rolling direction, may be 20 μm or less. By finely adjusting the grain size of ferrite, impact toughness may be obtained.

[0037] The non-quenched and tempered steel wire rod according to an embodiment of the present disclosure may satisfy Relational Expressions 1 to 5. In Relational Expressions 1 to 4, [Al], [N], [C], [S], [Mn], and [Si] respectively represent contents (wt%) of the elements.

[Relational Expression 1] $20 \leq \text{Mn/S} \leq 70$ (machinability)

[0038] Relational Expression 1 is an expression related to machinability. According to the present disclosure, MnS is formed by adding high contents of S and Mn. MnS, as an elongated inclusion, has a shape and an orientation elongated in a rolling direction and significantly improves machinability of the non-quenched and tempered steel wire rod of the present disclosure. However, MnS serving as a starting point of cracks and a propagation path thereof in the case of impact applied thereto, thereby deteriorating impact toughness. When the Mn/S ratio is less than 20, machinability may be satisfied, but impact toughness may deteriorate. When the Mn/S ratio exceeds 70, machinability may be insufficient. Therefore, the Mn/S ratio may be controlled to 20 to 70 in the present disclosure.

[Relational Expression 2] $1.4 \leq [\text{Al}]/[\text{N}] \leq 7$ (impact toughness)

[0039] Relational Expression 2 is an expression related to toughness. According to the present disclosure, AlN is formed by adding high contents of N and Al. Precipitation of fine AlN in a steel refines crystal grains to improve impact toughness of the non-quenched and tempered steel wire rod according to the present disclosure. In order to express the above-described effect, it is preferable to form AlN precipitates with a size of 50 nm or less as many as possible, and to this end, it is preferable to control the Al/N ratio within a range of 1.4 to 7. At an Al/N ratio less than 1.4, AlN precipitates cannot be sufficiently formed, and at an Al/N ratio exceeding 7, coarse AlN precipitates are formed, rather resulting in deterioration of impact toughness. Therefore, in the present disclosure, the Al/N ratio may be controlled in the range of 1.4 to 7, preferably 1.9 to 5.0, and more preferably 3.5 to 5.0.

[Relational Expression 3] $0.7 \leq \text{Mn} + \text{Cr} \leq 1.4$ (impact toughness)

[0040] Relational Expression 3 is an expression related to impact toughness. Mn and Cr refine the inter-layer spacing of pearlite to have an effect on improving toughness. The effect is sufficiently obtained when a sum of Mn and Cr is 0.7 or more. However, when the sum of Mn and Cr exceeds 1.4, a fraction of pearlite increases, resulting in an excessive increase in strength causing deterioration of impact toughness. Therefore, in the present disclosure, the sum of Mn and Cr is controlled in a range of 0.7 to 1.4, preferably 0.8 to 1.3, and more preferably 1.0 to 1.3.

[Relational Expression 4] $0.2 \leq \text{C/Mn} \leq 0.7$ (impact toughness)

[0041] Relational Expression 4 is an expression related to impact toughness. When the C/Mn ratio is less than 0.2, hard structures having a low toughness such as martensite or bainite are likely formed, resulting in deterioration of impact toughness. On the contrary, at a C/Mn ratio exceeding 0.7, an amount of pearlite with wide lamella spacing increases, resulting in deterioration of impact toughness. Therefore, the C/Mn ratio is controlled in a range of 0.2 to 0.7, preferably 0.3 to 0.6, and more preferably 0.4 to 0.5.

[Relational Expression 5] $0 \leq \text{Mn}_c/\text{Mn}_f \leq 3$ (cold workability)

[0042] Herein, Mn_c represents an average content (at%) of Mn contained in cementite in pearlite, and Mn_f represents an average content (at%) of Mn contained in ferrite in pearlite.

[0043] Relational Expression 5 is an expression related to cold workability and represents a Mn distribution ratio in pearlite. The Mn distribution ratio in pearlite is a value obtained by dividing an average content (at%) of Mn contained in cementite in pearlite by an average content (at%) of Mn contained in ferrite in pearlite. In the present disclosure, the Mn

distribution ratio in pearlite is controlled in a range of 0 to 3. The inventors have confirmed, through numerous experiments, that cold workability was improved in the case where the Mn distribution ratio in pearlite satisfied 3 or less, thereby completing the present disclosure. Because Mn is an element with a strong tendency to segregate into cementite in pearlite, common pearlite has a Mn distribution ratio of 5 or more. In order to control the Mn distribution ratio to 3 or less, distribution of Mn into cementite in pearlite should be inhibited, and the Mn distribution ratio in pearlite may be achieved by a cooling process, performed after the winding process, of applying different cooling rates to different temperature sections, respectively, according to the present disclosure.

[0044] In addition, the non-quenched and tempered steel material according to an embodiment of the present disclosure may have a tensile strength of 700 MPa or more.

[0045] In addition, the non-quenched and tempered steel material according to an embodiment of the present disclosure may have a yield strength of 350 to 500 MPa.

[0046] In addition, the non-quenched and tempered steel material according to an embodiment of the present disclosure may have a yield ratio of 0.45 to 0.65.

[0047] In addition, the non-quenched and tempered steel material according to an embodiment of the present disclosure may have an impact toughness of 60 J/cm² or more.

[0048] In addition, the non-quenched and tempered steel material according to an embodiment of the present disclosure may have a product of the tensile strength and the impact toughness of 45000 MPa·J/cm² or more.

[0049] Hereinafter, a method for manufacturing a non-quenched and tempered steel wire rod according to an embodiment of the present disclosure will be described.

[0050] A method for manufacturing a non-quenched and tempered steel wire rod with improved machinability and impact toughness according an embodiment of the present disclosure includes: reheating a steel piece including, in percent by weight (wt%), 0.3% to 0.5% of C, 0.4% to 0.9% of Si, 0.5% to 1.2% of Mn, 0.02% or less of P, 0.01% to 0.05% of S, 0.015% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.007% to 0.02% of N, and the remainder including Fe and inevitable impurities in a temperature range of 950°C to 1100°C; finish rolling the reheated steel piece into a steel wire rod at a temperature of 750°C to 850°C; and winding and cooling the steel wire rod, wherein the cooling performed after the winding includes: a first cooling process performed at an average cooling rate of 5 to 100°C/s from the finish rolling temperature to a winding temperature; a second cooling process performed after the first cooling process at an average cooling rate of 2 to 5°C/s from the winding temperature to 700°C; and

a third cooling process performed after the second cooling process at an average cooling rate of 0.1 to 2°C/s from 700°C to 450°C,

a microstructure of the steel wire rod includes ferrite and pearlite, and an average thickness of the pearlite layer in the L cross-section, which is a cross-section parallel to a rolling direction, is 30 μm or less.

[0051] In addition, according to an embodiment of the present disclosure, an average grain size of ferrite in the C cross-section, which is a cross-section perpendicular to the rolling direction, is 20 μm or less.

[0052] In addition, according to an embodiment of the present disclosure, Relational Expression 1 below may be satisfied.

$$[\text{Relational Expression 1}] \quad 20 \leq \text{Mn/S} \leq 70$$

[0053] In addition, according to an embodiment of the present disclosure, Relational Expression 2 below may be satisfied.

$$[\text{Relational Expression 2}] \quad 1.4 \leq \text{Al/N} \leq 7$$

[0054] In addition, according to an embodiment of the present disclosure, Relational Expression 3 below may be satisfied.

$$[\text{Relational Expression 3}] \quad 0.7 \leq \text{Mn} + \text{Cr} \leq 1.4$$

[0055] In addition, according to an embodiment of the present disclosure, Relational Expression 4 below may be satisfied.

$$[\text{Relational Expression 4}] \quad 0.2 \leq \text{C/Mn} \leq 0.7$$

[0056] In addition, according to an embodiment of the present disclosure, Relational Expression 5 below may be satisfied.

$$[\text{Relational Expression 5}] \quad 0 \leq \text{Mn}_c/\text{Mn}_f \leq 3$$

[0057] Hereinafter, each process of the manufacturing method will be described in more detail.

[0058] First, a bloom satisfying the above-described composition of alloying elements is heated and rolled into a billet.

Reheating Process

[0059] The reheating process, as a process of reheating the rolled billet, is a process for lowering a rolling load while rolling the steel wire rod. In this regard, the reheating process may be performed in the temperature range of 950°C to 1120°C. At a reheating temperature below 950°C, the rolling load may increase causing difficulties in the manufacturing method. On the contrary, at a reheating temperature above 1,100°C, AlN formed in the steel piece turns to a solid solution again during heating, so that grain refinement effect by the AlN may significantly decrease.

Process of Rolling Steel Wire Rod

[0060] In the process of rolling the steel wire rod, the reheated steel piece is hot-rolled into a steel wire rod. In this case, a finish rolling temperature of the hot rolling may be 750°C to 850°C. At a finish rolling temperature below 750°C, a rolling load may increase, and at a finish rolling temperature above 850°C, crystal grains may coarsen so that a high toughness desired in the present disclosure may not be obtained.

Winding Process

[0061] A process of winding the steel wire rod manufactured as described above in the shape of a coil may be performed. In this case, a winding temperature may be 750°C to 850°C. Because a temperature of the steel wire rod obtained by finish rolling may increase by transformation heating, a temperature of the steel wire rod immediately before winding may be higher than a final rolling temperature. In this case, the steel wire rod may be wound after being cooled to the winding temperature or may be wound without an additional cooling process depending on the temperature increased by the heating. At a winding temperature below 750°C, martensite generated in the surface layer during cooling cannot be recovered due to double rows, and tempered martensite is formed causing a problem of increasing a potential to induce surface defects during a drawing process. On the contrary, at a winding temperature above 850°C, thick scales may be formed on the surface of the steel wire rod so that surface defects may easily occur during descaling and productivity may deteriorate due to an increase in cooling time in a subsequent cooling process.

Cooling Process

[0062] The cooling process, as a process of obtaining the non-quenched and tempered steel wire rod according to the present disclosure by cooling the steel wire rod after final rolling and winding, is a process of controlling the above-described distribution ratio of Mn contained in cementite and ferrite in pearlite. In order to control the Mn distribution ratio of cementite in pearlite to 3 or less, distribution of Mn needs to be inhibited as much as possible during the cooling process. In order to inhibit the distribution of Mn into cementite as much as possible, it is effective for applying different cooling rates to different temperature sections.

First Cooling Process (CR1): Final rolling temperature to Winding temperature

[0063] The first cooling process may be performed at an average cooling rate of 5°C/s to 100°C/s from the final rolling temperature to the winding temperature. Since Mn diffuses very rapidly in the temperature section of the first cooling process, there is a high possibility that the Mn distribution ratio exceeds 3 at a cooling rate lower than 5°C/s, and it is difficult to commercially apply a cooling rate higher than 100°C/s. Therefore, the first cooling process may be performed at a cooling rate of 5°C/s to 100°C/s.

Second Cooling Process (CR2): Winding temperature to 700°C

[0064] The second cooling process may be performed after the first cooling process at an average cooling rate of 2°C/s to 5°C/s from the winding temperature to 700°C. At a cooling rate lower than 2°C/s, the Mn distribution ratio may exceed 3

due to diffusion of Mn, and at a cooling rate higher than 5°C/s, a non-uniform material such as mixed material may be obtained due to non-uniform cooling. Therefore, the second cooling process may be performed at a cooling rate of 2°C/s to 5°C/s.

Third Cooling Process (CR3): 700 to 450°C

[0065] The third cooling process may be performed after the second cooling process at an average cooling rate of 0.1°C/s to 2°C/s from 700°C to 450°C. At a cooling rate lower than 0.1°C/s, lamella spacing of pearlite coarsens, so that it is difficult to obtain strength desired in the present disclosure, and at a cooling rate higher than 2°C/s, a low-temperature bainite structure may be formed during the cooling. Therefore, the third cooling process may be performed at a cooling rate of 0.1°C/s to 2°C/s.

[0066] 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}

[0067] Each of the blooms having a composition of alloying elements shown in Table 1 was heated at 1,200°C for 4 hours, and rolled into a billet at a finish rolling temperature of 1,100°C. Then, the billet was heated at 1,100°C for 90 minutes and hot-rolled into a steel wire rod at a finish rolling temperature of 800°C using a 25 mm-roll. Subsequently, the three-step cooling process including CR1-CR2-CR3 temperature sections was applied thereto to manufacture steel wire rod specimens of Examples 1 to 7 and Comparative Examples 1 to 13. Then, microstructures of the cooled steel wire rod specimens and Mn distribution ratios of ferrite/cementite were shown in Table 2 below, and tensile strength and impact toughness properties thereof were measured and shown in Table 3 below.

[0068] Here, room-temperature tensile strength was measured at the center of the specimens of the non-quenched and tempered steels at 25°C, and room-temperature impact toughness was measured from the specimens having a U-notch (based on a standard sample, 10x10x55 mm) at 25°C using a Charpy impact energy value obtained by the Charpy impact test.

[0069] In addition, in order to evaluate machinability, the steel wire rod having a diameter of 26 mm was processed with a reduction rate of 14.8% into a cold drawn bar (CD-Bar) with a diameter of 24 mm. The machinability was evaluated by using a CNC lathe, and breakability of turned chips was evaluated after performing turning operations until the diameter of 24 mm of the CD-Bar decreased to a diameter of 15 mm. In this case, cutting was performed under the conditions of a cutting rate of 100 mm/min, a feedrate of 0.1 mm/rev, and a cutting depth of 1.0 mm by using a cutting oil. Breakability of cut chips was evaluated based on the number of the cut chips produced during a turning process, 5 or less of cut chips was evaluated as good, more than 5 but not more than 10 of cut chips was evaluated as fair, and more than 10 cut chips was evaluated as poor, and the results are shown in Table 3.

[0070] In addition, an average thickness of the pearlite layer was obtained by calculating an arithmetic mean from 30 images obtained at 200x magnification at points corresponding to the quarter of the diameter of the steel wire rod, and the average grain size of ferrite refers to a value corresponding to an equivalent circular diameter.

[Table 1]

Category	Chemical composition of alloying elements (wt%)								Relational Expression			
	C	Si	Mn	P	S	Al	Cr	N	(1)	(2)	(3)	(4)
Inventive Steel 1	0.44	0.84	1.12	0.0185	0.025	0.050	0.21	0.0196	44.3	2.5	1.3	0.4
Inventive Steel 2	0.35	0.90	0.75	0.0067	0.021	0.044	0.26	0.0132	35.2	3.3	1.0	0.5
Inventive Steel 3	0.34	0.62	0.87	0.0052	0.017	0.043	0.12	0.0129	51.8	3.3	1.0	0.4
Inventive Steel 4	0.41	0.66	0.89	0.0001	0.015	0.040	0.17	0.0165	61.0	2.4	1.1	0.5
Inventive Steel 5	0.45	0.90	1.05	0.0175	0.027	0.040	0.13	0.0109	38.7	3.7	1.2	0.4

(continued)

	Category	Chemical composition of alloying elements (wt%)								Relational Expression			
		C	Si	Mn	P	S	Al	Cr	N	(1)	(2)	(3)	(4)
5	Inventive Steel 6	0.30	0.90	1.08	0.0195	0.046	0.038	0.10	0.0140	23.4	2.7	1.2	0.3
	Inventive Steel 7	0.48	0.59	0.75	0.0151	0.025	0.019	0.24	0.0095	30.2	1.9	1.0	0.6
10	Comparative Steel 1	<u>0.21</u>	0.61	0.64	0.0127	0.015	0.049	0.18	0.019	41.6	2.6	0.8	0.3
	Comparative Steel 2	0.49	<u>1.20</u>	1.00	0.0117	0.049	0.037	0.22	0.011	20.4	3.3	1.2	0.5
15	Comparative Steel 3	0.39	0.74	<u>1.22</u>	0.0171	0.045	0.044	0.15	0.019	26.9	2.4	1.4	0.3
	Comparative Steel 4	0.36	0.66	0.53	0.0140	<u>0.009</u>	0.040	0.23	0.010	57.0	4.1	0.8	0.7
20	Comparative Steel 5	0.34	0.76	0.86	0.0045	0.020	0.028	0.24	<u>0.005</u>	43.2	5.6	1.1	0.4
	Comparative Steel 6	0.32	0.40	0.71	0.0106	0.041	0.021	0.18	0.014	<u>17.4</u>	1.6	0.9	0.5
25	Comparative Steel 7	0.49	0.70	0.86	0.0013	0.026	0.022	0.17	0.017	33.6	<u>1.3</u>	1.0	0.6
	Comparative Steel 8	0.47	0.41	1.17	0.0027	0.019	0.037	0.30	0.009	60.9	3.9	<u>1.5</u>	0.4
30	Comparative Steel 9	0.47	0.45	0.55	0.0048	0.011	0.016	0.30	0.010	50.5	1.7	0.9	<u>0.9</u>

[Table 2]

	Category	Steel type	Heating temperature(°C)	Cooling rate (°C/s)			Thick ness of pearlite (μm)	Average size of ferrite (μm)	Cementite/p earlite Mn distribution ratio (Relational Exp.(5))
				CR1	CR2	CR3			
35	Example 1	Inventive Steel 1	1090	20	2.5	0.5	20	15	1.5
40	Example 2	Inventive Steel 2	1090	20	3.0	1.0	14	16	1.0
45	Example 3	Inventive Steel 3	1090	10	4.0	1.5	12	12	1.1
	Example 4	Inventive Steel 4	1090	10	4.0	0.2	15	17	2.5
50	Example 5	Inventive Steel 5	1090	15	2.5	0.5	14	16	2.0
	Example 6	Inventive Steel 6	1090	10	3.0	1.0	13	17	2.5
55	Example 7	Inventive Steel 7	1090	30	4.5	1.5	13	15	0.9

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(continued)

Category	Steel type	Heating temperature(°C)	Cooling rate (°C/s)			Thickness of pearlite (μm)	Average size of ferrite (μm)	Cementite/pearlite Mn distribution ratio (Relational Exp.(5))
			CR1	CR2	CR3			
Comparative Example 1	Comparative Steel 1	1090	30	2.5	0.5	20	13	1.4
Comparative Example 2	Comparative Steel 2	1090	20	3.0	1.0	15	12	1.7
Comparative Example 3	Comparative Steel 3	1090	40	2.5	1.0	14	16	2.5
Comparative Example 4	Comparative Steel 4	1090	20	3.0	1.5	16	12	2.4
Comparative Example 5	Comparative Steel 5	1090	30	3.0	1.5	14	<u>23</u>	0.5
Comparative Example 6	Comparative Steel 6	1090	20	4.0	0.5	16	14	2.7
Comparative Example 7	Comparative Steel 7	1090	20	3.5	1.5	25	15	2.3
Comparative Example 8	Comparative Steel 8	1090	10	2.5	1.0	26	18	2.7
Comparative Example 9	Comparative Steel 9	1090	20	3.0	1.0	17	19	2.5
Comparative Example 10	Inventive Steel 1	1090	20	<u>0.5</u>	1.0	<u>32</u>	15	<u>4.3</u>
Comparative Example 11	Inventive Steel 2	1090	10	<u>20.0</u>	<u>10.0</u>	15	14	1.8
Comparative Example 12	Inventive Steel 3	1090	<u>0.1</u>	3.0	1.0	<u>35</u>	<u>22</u>	<u>5.0</u>
Comparative Example 13	Inventive Steel 3	<u>1150</u>	20	3.0	1.0	27	<u>23</u>	1.7

[Table 3]

	Steel type	Tensile strength (MPa)	Yield strength (MPa)	Yield ratio	Impact toughness (J/cm ²)	Tensile strength x impact toughness (MPa·J/cm ²)	Chip breakability
Example 1	Inventive Steel 1	891	465	0.52	61	54371	good
Example 2	Inventive Steel 2	768	419	0.55	70	53771	good
Example 3	Inventive Steel 3	761	425	0.56	71	53896	good
Example 4	Inventive Steel 4	836	431	0.52	63	52282	good
Example 5	Inventive Steel 5	891	480	0.54	61	54599	good

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(continued)

	Steel type	Tensile strength (MPa)	Yield strength (MPa)	Yield ratio	Impact toughn ess (J/cm ²)	Tensile strength x impact toughness (MPa·J/cm ²)	Chip breakabil ity
Example 6	Inventive Steel 6	717	403	0.56	75	53567	good
Example 7	Inventive Steel 7	848	472	0.56	65	55212	good
Comparative Example 1	Comparative Steel 1	<u>611</u>	<u>333</u>	0.55	86	52405	good
Comparative Example 2	Comparative Steel 2	833	457	0.55	<u>40</u>	<u>33330</u>	good
Comparative Example 3	Comparative Steel 3	806	417	0.52	<u>55</u>	<u>44331</u>	good
Comparative Example 4	Comparative Steel 4	748	402	0.54	<u>58</u>	<u>43383</u>	good
Comparative Example 5	Comparative Steel 5	766	421	0.55	<u>59</u>	45184	good
Comparative Example 6	Comparative Steel 6	<u>642</u>	356	0.56	84	53876	<u>poor</u>
Comparative Example 7	Comparative Steel 7	882	479	0.54	<u>58</u>	51182	good
Comparative Example 8	Comparative Steel 8	899	<u>511</u>	0.57	61	55270	good
Comparative Example 9	Comparative Steel 9	827	457	0.55	<u>58</u>	47952	good
Comparative Example 10	Inventive Steel 1	891	496	0.56	<u>57</u>	50722	good
Comparative Example 11	Inventive Steel 2	901	412	0.46	<u>35</u>	<u>31535</u>	good
Comparative Example 12	Inventive Steel 3	<u>695</u>	395	0.57	<u>58</u>	<u>40310</u>	good
Comparative Example 13	Inventive Steel 3	761	407	0.54	<u>50</u>	<u>38060</u>	good

[0071] Specifically, the steel wire rods of Examples 1 to 7 satisfying all of the chemical composition, the relational expressions, and the manufacturing conditions provided in the present disclosure, satisfied a tensile strength of 700 MPa or more, a room-temperature impact toughness of 60 J/cm² or more, and a tensile strength x impact toughness value of 45000 MPa·J/cm² or more, and machinability. On the contrary, the steel wire rods of Comparative Examples 1 to 5 out of the chemical composition could not satisfy one or more of the values. Although Comparative Examples 6 to 9 satisfied the chemical composition suggested by the present disclosure, the values of the relational expressions were out of the suggested values, so as to fail to physical properties desired herein. In addition, in the case of Comparative Examples 10 to 13 not satisfying the heating temperature and cooling conditions among the manufacturing conditions, both the target tensile strength and impact toughness could not be satisfied.

[Industrial Applicability]

[0072] According to the present disclosure, a non-quenched and tempered steel wire having excellent machinability and impact toughness may be obtained without additional heat treatment, and therefore the present disclosure has industrial applicability.

Claims

1. A non-quenched and tempered steel wire rod with improved machinability and impact toughness comprising, in percent by weight (wt%), 0.3% to 0.5% of C, 0.4% to 0.9% of Si, 0.5% to 1.2% of Mn, 0.02% or less of P, 0.01% to 0.05% of S, 0.015% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.007% to 0.02% of N, and the remainder including Fe and inevitable impurities, wherein a microstructure ferrite and pearlite, and an average thickness of the pearlite layer in a L cross-section, which is parallel to a rolling direction, is 30 μm or less.

2. The non-quenched and tempered steel wire rod according to claim 1, wherein an average grain size of ferrite in a C cross-section, which is perpendicular to the rolling direction, is 20 μm or less.

3. The non-quenched and tempered steel wire rod according to claim 1, wherein Relational Expression 1 below is satisfied:

$$[\text{Relational Expression 1}] \quad 20 \leq \text{Mn}/\text{S} \leq 70.$$

4. The non-quenched and tempered steel wire rod according to claim 1, wherein Relational Expression 2 below is satisfied:

$$[\text{Relational Expression 2}] \quad 1.4 \leq \text{Al}/\text{N} \leq 7.$$

5. The non-quenched and tempered steel wire rod according to claim 1, wherein Relational Expression 3 below is satisfied:

$$[\text{Relational Expression 3}] \quad 0.7 \leq \text{Mn} + \text{Cr} \leq 1.4.$$

6. The non-quenched and tempered steel wire rod according to claim 1, wherein Relational Expression 4 below is satisfied:

$$[\text{Relational Expression 4}] \quad 0.2 \leq \text{C}/\text{Mn} \leq 0.7.$$

7. The non-quenched and tempered steel wire rod according to claim 1, wherein Relational Expression 5 below is satisfied:

$$[\text{Relational Expression 5}] \quad 0 \leq \text{Mn}_c/\text{Mn}_f \leq 3$$

(wherein Mn_c represents an average content (at%) of Mn contained in cementite in pearlite, and Mn_f represents an average content (at%) of Mn contained in ferrite in pearlite.)

8. The non-quenched and tempered steel wire rod according to claim 1, wherein a tensile strength is 700 MPa or more.

9. The non-quenched and tempered steel wire rod according to claim 1, wherein a yield strength is 350 MPa to 500MPa.

10. The non-quenched and tempered steel wire rod according to claim 1, wherein a yield ratio is 0.45 to 0.65.

11. The non-quenched and tempered steel wire rod according to claim 1, wherein a room-temperature impact toughness is 60 J/cm² or more.

12. The non-quenched and tempered steel wire rod according to claim 1, wherein a product of the tensile strength and the room-temperature impact toughness is 45000 MPa·J/cm² or more.

13. A method for manufacturing a non-quenched and tempered steel wire rod with improved machinability and impact toughness, the method comprising:

reheating a steel piece including, in percent by weight (wt%), 0.3% to 0.5% of C, 0.4% to 0.9% of Si, 0.5% to 1.2% of Mn, 0.02% or less of P, 0.01% to 0.05% of S, 0.015% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.007% to 0.02% of N, and the remainder including Fe and inevitable impurities in a temperature range of 950°C to 1100°C; finish rolling the reheated steel piece into a steel wire rod at a temperature of 750°C to 850°C; and winding and cooling the steel wire rod, wherein the cooling performed after the winding comprises:

a first cooling process performed at an average cooling rate of 5°C/s to 100°C/s from the finish rolling temperature to a winding temperature;

a second cooling process performed after the first cooling process at an average cooling rate of 2°C/s to 5°C/s from the winding temperature to 700°C; and

a third cooling process performed after the second cooling process at an average cooling rate of 0.1°C/s to 2°C/s from 700°C to 450°C,

wherein a microstructure of the steel wire rod comprises ferrite and pearlite, and an average thickness of the pearlite layer in a L cross-section, which is parallel to a rolling direction, is 30 μm or less.

14. The method according to claim 13, wherein an average grain size of ferrite in a C cross-section, which is perpendicular to the rolling direction, is 20 μm or less.

15. The method according to claim 13, wherein Relational Expression 1 below is satisfied:

$$[\text{Relational Expression 1}] \quad 20 \leq \text{Mn/S} \leq 70.$$

INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2023/007440

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/18(2006.01)i; C22C 38/00(2006.01)i; B21B 1/16(2006.01)i; C21D 8/06(2006.01)i; C21D 9/52(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 38/18(2006.01); B21B 1/16(2006.01); C21D 8/00(2006.01); C21D 8/02(2006.01); C22C 38/00(2006.01);
C22C 38/06(2006.01); C22C 38/26(2006.01); C22C 38/38(2006.01)

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: 비조질(non-heat treated), 봉재(rod), 냉각(cooling), 페라이트(ferrite), 펄라이트
(pearlite), 권취(coiling)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	KR 10-2021-0077530 A (POSCO) 25 June 2021 (2021-06-25) See paragraph [0104], claims 1 and 8-10, tables 2-3 and figure 1.	1-6,8-12 7,13-20
X	KR 10-2020-0062439 A (POSCO) 04 June 2020 (2020-06-04) See claims 1-3, 8 and 10-12, tables 2-3 and figure 1.	1-6,8-12
A	KR 10-2175586 B1 (POSCO) 06 November 2020 (2020-11-06) See claims 7-8.	1-20
A	JP 2004-137542 A (SUMITOMO METAL IND. LTD.) 13 May 2004 (2004-05-13) See claims 1-4.	1-20
A	KR 10-2178711 B1 (POSCO) 13 November 2020 (2020-11-13) See claims 1 and 5-7 and figure 1.	1-20

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

* Special categories of cited documents:	"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
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Date of the actual completion of the international search 20 September 2023	Date of mailing of the international search report 20 September 2023
Name and mailing address of the ISA/KR Korean Intellectual Property Office Government Complex-Daejeon Building 4, 189 Cheongsaro, Seo-gu, Daejeon 35208	Authorized officer
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Form PCT/ISA/210 (second sheet) (July 2022)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2023/007440

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KR 10-2178711 B1	13 November 2020	None	