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

(57) Provided are a non-quenched and tempered steel rod wire with improved machinability and toughness and a method for manufacturing the same.

The non-quenched and tempered steel 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, 0.01% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.01% to 0.02% of Ti, 0.0005% to 0.002% of Ca, 0.007% to 0.02% of N, and the remainder being Fe and inevitable impurities, and includes ferrite and pearlite as microstructures and satisfies Relational Expression 1 below:

$$\text{[Relational Expression 1] } 2 \leq (\mathrm{Al}+\mathrm{Ti})/\mathrm{N} \leq 5.$$

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Description

[Technical Field]

[0001] The present disclosure relates to a non-quenched and tempered steel rod wire with improved machinability and impact toughness and a method for manufacturing the same, and more particularly, to a non-quenched and tempered steel rod wire 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 CO_2 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 steel. However, with a recent increase in the demand for environmental feasibility and cost reduction, demand for improving toughness of non-quenched and tempered steel 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] The present disclosure provides a non-quenched and tempered steel rod wire whose toughness, inferior to that of conventional quenched and tempered steels, is improved and having both impact toughness and machinability by decreasing grain sizes via TiN and AlN formation and inhibiting elongation of MnS via Ca addition without additional heat treatment, and a method for manufacturing same.

[Technical Solution]

[0004] A non-quenched and tempered steel rod wire 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, 0.01% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.01% to 0.02% of Ti, 0.0005% to 0.002% of Ca, 0.007% to 0.02% of N, and the remainder being Fe and inevitable impurities, also includes ferrite and pearlite as microstructures, and satisfies Relational Expression 1 below.

$$\text{[Relational Expression 1] } 2 \leq (\mathrm{Al}+\mathrm{Ti})/\mathrm{N} \leq 5$$

[0005] A method for manufacturing a non-quenched and tempered steel rod wire 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, 0.01% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.01% to 0.02% of Ti, 0.0005% to 0.002% of Ca, 0.007% to 0.02% of N, and the remainder being Fe and inevitable impurities in a temperature range of 950°C to 1120°C; finish rolling the reheated steel piece into a steel rod wire at a temperature of 750°C to 850°C; and winding the steel rod wire and cooling the steel rod wire to 400°C in an average cooling rate range of 0.1°C/s to 5.0°C/s.

[Advantageous Effects]

[0006] In the non-quenched and tempered steel rod wire with improved machinability and impact toughness according to an embodiment of the present disclosure, Ti and Al combine with N to form nitrides such as TiN and AlN, and such nitrides interfere with the growth of grain boundaries to decrease grain sizes, thereby improving toughness. In addition, a Ca-based oxide resulting from addition of Ca serves as a nucleus of MnS formation and inhibits elongation of MnS during rolling to improve machinability and toughness. Therefore, even if heat treatment is omitted, the steel rod wire may be applied to materials for automobiles or mechanical parts that require both machinability and toughness.

[Best Model

[0007] A non-quenched and tempered steel rod wire 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, 0.01% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.01% to 0.02% of Ti, 0.0005% to 0.002% of Ca, 0.007% to 0.02% of N, and the remainder being Fe and inevitable impurities, also includes ferrite and pearlite as microstructures, and satisfies Relational Expression 1 below.

$$[\text{Relational Expression 1}]\ 2 \leq (\text{Al+Ti})/\text{N} \leq 5$$

[Modes of the Invention]

[0008] 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, the present disclosure will be described in detail.
[0009] The present inventors have examined a method for providing a steel rod wire with machinability and impact toughness from various angles and have found that machinability and toughness may be obtained by appropriately controlling a composition of alloying elements and a microstructure of the steel rod wire without a separate heat treatment, thereby completing the present disclosure.
[0010] A non-quenched and tempered steel rod wire 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, 0.01% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.01% to 0.02% of Ti, 0.0005% to 0.002% of Ca, 0.007% to 0.02% of N, and the remainder being Fe and inevitable impurities and satisfies Relational Expression 1 below.

$$[\text{Relational Expression 1}]\ 2 \leq (\text{Al+Ti})/\text{N} \leq 5$$

[0011] Hereinafter, reasons for numerical limitations on the contents of alloying elements in the embodiment of the present disclosure will be described. Hereinafter, the unit is wt% unless otherwise stated.
[0012] The content of C is 0.3% to 0.5%.
[0013] Carbon (C) is an element serving to improve strength of a steel rod wire. 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%.
[0014] The content of Si is 0.4% to 0.9%.
[0015] 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. Therefore, the upper limit of the Si content may be controlled to 0.9%.
[0016] The content of Mn is 0.5% to 1.2%.
[0017] 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. Therefore, the upper limit of the Mn content may be controlled to 1.2%.
[0018] The content of Cr is 0.1% to 0.3%.
[0019] 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 strain 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%.
[0020] The content of P is 0.02% or less.
[0021] Phosphorus (P), as an impurity inevitably contained in steels, is a major causative element of segregation into grain boundaries resulting in 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 therein 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.

[0022] The content of S is 0.01% to 0.05%.

[0023] Sulfur (S), as a major causative element of segregation into grain boundaries resulting in significant deterioration in ductility and formation of sulfide inclusions in a steel resulting in deterioration in delayed fracture resistance and stress relaxation, 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.

[0024] The content of sol.Al is 0.01% to 0.05%.

[0025] The sol.Al is an element effective as a deoxidizer. The sol.Al may be contained in an amount of 0.01% to obtain the above-describe effect. However, with an Al content exceeding 0.05%, difficulties may arise during a casting process due to Al oxides. Therefore, the upper limit of the Al content may be controlled to 0.05% in the present disclosure.

[0026] The content of Ti is 0.01% to 0.02%.

[0027] Titanium (Ti) is an element that plays a major role in improving toughness of a steel by decreasing grain sizes of a final structure by forming TiN precipitates during a solidification process of the steel to inhibit the growth of austenite crystal grains during heating and hot rolling processes of a slab. With a Ti content less than 0.01%, it is difficult to obtain a sufficient amount of TiN precipitates to inhibit migration of austenite grain boundaries. On the contrary, with a T content exceeding 0.02%, a coarse titanium nitride may be formed rather deteriorating toughness, and thus the upper limit of the Al content may be controlled to 0.02% in the present disclosure.

[0028] The content of Ca is 0.0005% to 0.002%.

[0029] Ca is an essential element to implement an effect on improving machinability and impact toughness by reducing an aspect ratio of MnS. Addition of Ca causes formation of an oxide, which serves as a nucleus of MnS, to inhibit elongation of MnS while rolling the steel rod wire and maintain a low aspect ratio. The low aspect ratio of MnS not only improves machinability but also inhibits deterioration of toughness by reducing anisotropy of a microstructure. However, Ca should be added in an amount of 0.0005% or more to obtain the above-described effects, but a Ca content exceeding 0.002% may cause difficulties in a manufacturing process. Therefore, the upper limit of the Ca content is controlled to 0.002%

[0030] The content of N is 0.007% to 0.02%.

[0031] N is an essential element for implementing an effect on improving impact toughness by decreasing grain sizes via formation of a nitride with Ti and 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 precipitates of Al, Ti, and the like, 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 rod wire. Therefore, the upper limit of the N content may be controlled to 0.02% in the present disclosure.

[0032] The remaining component of the non-quenched and tempered steel rod wire of the present disclosure is iron (Fe). However, the non-quenched and tempered steel rod wire 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.

[0033] The non-quenched and tempered steel rod wire according to an embodiment of the present disclosure may satisfy Relational Expressions 1 to 3.

[0034] In Relational Expressions 1 to 3, [Al], [Ti], [N], [S], [Ca], [C], [Si], and [Mn] respectively represent the elements and contents (wt%) thereof.

[0035]

$$\text{[Relational Expression 1] } 2 \leq ([Al]+[Ti])/[N] \leq 5 \text{ (toughness)}$$

[0036] Relational Expression 1 is an expression related to toughness. According to the present disclosure, TiN and AlN are formed by adding high contents of N, Ti, and Al. Because precipitation of fine TiN and AlN in the steel inhibits the growth of crystal grains, grains are refined to improve impact toughness of the non-quenched and tempered steel rod wire according to the present disclosure. It is preferably to form TiN and AlN precipitates with a size of about 50 nm as many as possible to obtain the above-described effects, and to this end, the ([Al]+[Ti])/[N] ratio needs to be controlled in a range of 2 to 5. At a ([Al]+[Ti])/[N] ratio less than 2, the precipitates cannot be formed sufficiently. At a ([Al]+[Ti])/[N] ratio exceeding 5 may cause formation of coarse precipitates rather resulting in deterioration of toughness. Therefore, according to the present disclosure, the ([Al]+[Ti])/[N] ratio is controlled in the range of 2 to 5.

$$\text{[Relational Expression 2] } 10 \leq [S]/[Ca] \leq 70$$

(machinability and impact toughness)

[0037] Relational Expression 2 is an expression related to machinability and impact toughness. According to the present disclosure, MnS is formed by adding a high S content. 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 rod wire 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. Therefore, Ca is added to inhibit elongation of MnS, and to this end, it is preferable to control the S/Ca ratio in the range of 10 to 70. At a S/Ca ratio less than 10, machinability desired in the present disclosure is difficult to obtain due to the insufficient content of S relative to that of Ca. On the contrary, at a S/Ca ratio exceeding 70, elongation of MnS is not effectively inhibited because a sufficient amount of the Ca oxide capable of inhibiting elongation of MnS is not obtained, so that it is difficult to obtain toughness. Therefore, the S/Ca ratio is controlled in the range of 10 to 70 to obtain a combination of excellent machinability and impact toughness in the present disclosure.

$$700 \leq 300 + 903X[C] + 95X[Si] + 154X[Mn] - 2303X[S] \text{ (strength)} \qquad \text{[Relational Expression 3]}$$

[0038] Relational Expression 3 is an expression related to strength. C, Si, and Mn are elements with great solid solution strengthening effects. On the contrary, because S forms MnS to decrease an amount of Mn effective for contributing to solid solution strengthening, strength decreases. Therefore, the value of Relational Expression 3 needs to be controlled to 700 or more to obtain a strength of the steel rod wire of 700MPa or more.

[0039] The non-quenched and tempered steel rod wire according to an embodiment of the present disclosure includes ferrite and pearlite as microstructures, and an average inter-layer spacing between ferrite and pearlite may be 10.0 to 15.0 μm, preferably, 12.0 to 13.0 μm.

[0040] In addition, the non-quenched and tempered steel rod wire according to an embodiment of the present disclosure may have a ferrite's thickness of 5.0 to 10.0 μm, preferably, 7.0 to 9.0 μm.

[0041] In addition, the non-quenched and tempered steel rod wire according to an embodiment of the present disclosure may have a ferrite's aspect ratio of 4 or less.

[0042] In addition, the non-quenched and tempered steel rod wire according to an embodiment of the present disclosure may have a tensile strength of 700 MPa or more.

[0043] In addition, the non-quenched and tempered steel rod wire according to an embodiment of the present disclosure may have a yield strength of 350 to 450 MPa.

[0044] In addition, the non-quenched and tempered steel rod wire according to an embodiment of the present disclosure may have a yield ratio of 0.45 to 0.65.

[0045] In addition, the non-quenched and tempered steel rod wire according to an embodiment of the present disclosure may have an impact toughness of 60 J/cm^2 or more.

[0046] In addition, the non-quenched and tempered steel rod wire according to an embodiment of the present disclosure may have a product of tensile strength and impact toughness of 30000 to 60000.

[0047] Hereinafter, a method for manufacturing a non-quenched and tempered steel rod wire according to an embodiment of the present disclosure will be described.

[0048] The non-quenched and tempered steel rod wire with improved machinability and impact toughness according to the present disclosure may be manufactured by using various methods, and the methods are not particularly limited. However, the steel rod wire may be manufactured by using the following method according to an embodiment.

[0049] A method for manufacturing a non-quenched and tempered steel rod wire with improved machinability and impact toughness according to 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, 0.01% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.01% to 0.02% of Ti, 0.0005% to 0.002% of Ca, 0.007% to 0.02% of N, and the remainder being Fe and inevitable impurities, and also including ferrite and pearlite as microstructures; hot rolling the reheated steel piece into a steel rod wire; and winding and cooling the steel rod wire.

[0050] Hereinafter, each process of the manufacturing method will be described in more detail.

[0051] First, a bloom satisfying the above-described composition of alloying elements is heated and rolled into a billet.

Reheating Process

[0052] The reheating process, as a step of reheating the rolled billet, is a process for lowering a rolling load while rolling the steel rod wire. In this regard, the reheating may be performed at a temperature 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 1,120°C, all AlN finely formed in the pieces of the steel may form a solid solution again during heating, thereby significantly decreasing a grain refinement effect.

Process of Rolling Steel Rod Wire

[0053] In the process of rolling the steel rod wire, the reheated pieces of the steel are hot-rolled into a steel rod wire.

[0054] 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

[0055] A process of winding the steel rod wire 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 rod wire obtained by finish rolling may increase by transformation heating, a temperature of the steel rod wire immediately before winding may be higher than a final rolling temperature. In this case, the steel rod wire may be wound after being cooled to a winding temperature or may be wound without a separate cooling process depending on the temperature increased by the heating. At a winding temperature below 750°C, martensite generated in a surface layer during cooling cannot be recovered due to residual heat, 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 rod wire 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

[0056] The wound steel rod wire may be cooled, and in this case, the cooling process may be performed to 400°C in an average cooling rate range of 0.1°C/s to 5.0°C/s by air cooling or control cooling after hot forging. At an average cooling rate lower than 0.1°C/s while cooling to 400°C after winding, a desired strength cannot be obtained due to excessive formation of proeutectoid ferrite. At an average cooling rate higher than 5°C/s, low-temperature structures such as martensite may be generated, and thus toughness and machinability may deteriorate.

{Examples}

[0057] A bloom 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 1090°C for 90 minutes, finish-rolled at 800°C, wound at 780°C, and cooled into a steel rod wire having a diameter of 26 mm. Steel rod wires including components of Inventive Steels 1 to 7 and Comparative Steels 1 to 4 were manufactured (Table 1) and tensile strength and impact toughness of samples of the steel rod wires were measured and shown in Table 2 below.

[0058] Here, room-temperature tensile strength was measured at the center of the samples of the non-quenched and tempered steels at 25°C, and room-temperature impact toughness was measured at the samples 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.

[0059] In addition, in order to evaluate machinability, the steel rod wire having a diameter of 26 mm were processed with a reduction rate of 14.8% into cold drawn bars (CD-Bars) with a diameter of 24 mm. The machinability was evaluated by using a CNC lathe, and fragmentation of turned chips was evaluated after performing turning operations until the diameter of 24 mm of CD-Bars 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 feed rate of 0.1 mm/rev, and a cutting depth of 1.0 mm by using a cutting oil. Fragmentation of cut chips was evaluated based on the number of turns 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.

[Table 1]

Category	Chemical composition of alloying elements (wt%)										Relational expression		
	C	Si	Mn	P	S	Al	Cr	Ti	Ca	N	(1)	(2)	(3)
Inventive Steel 1	0.45	0.69	0.97	0.0092	0.030	0.038	0.16	0.011	0.0010	0.0098	5.0	30	852
Inventive Steel 2	0.43	0.69	0.68	0.0109	0.024	0.032	0.16	0.016	0.0015	0.0173	2.8	16	803

(continued)

Category	Chemical composition of alloying elements (wt%)										Relational expression		
	C	Si	Mn	P	S	Al	Cr	Ti	Ca	N	(1)	(2)	(3)
Inventive Steel 3	0.31	0.83	0.96	0.0000	0.036	0.028	0.27	0.014	0.0010	0.0172	2.4	35	723
Inventive Steel 4	0.49	0.45	0.99	0.0120	0.023	0.038	0.21	0.019	0.0017	0.0172	3.3	13	884
Inventive Steel 5	0.45	0.76	0.76	0.0059	0.039	0.036	0.18	0.019	0.0011	0.0099	5.6	35	806
Inventive Steel 6	0.40	0.78	0.93	0.0169	0.043	0.010	0.18	0.017	0.0009	0.0118	2.3	50	779
Inventive Steel 7	0.39	0.81	0.93	0.0040	0.012	0.025	0.27	0.015	0.0009	0.0140	2.8	13	846
Comparative Steel 1	0.20	0.41	0.78	0.0166	0.024	0.050	0.22	0.015	0.0015	0.0170	3.8	16	**630**
Comparative Steel 2	0.46	1.20	1.15	0.0000	0.017	0.030	0.30	0.016	0.0020	0.0100	4.6	**8**	968
Comparative Steel 3	0.30	0.43	0.20	0.0036	0.041	0.038	0.18	0.011	0.0019	0.0130	3.8	22	**547**
Comparative Steel 4	0.30	0.40	1.08	0.0074	0.019	0.048	0.21	0.040	0.0018	0.0114	***7.7***	11	731

[Table 2]

Category	Steel type	Heating temperature of steel piece (°C)	Average cooling rate to 400°C (°C/s)	Tensile strength (MPa)	Room-temperature impact toughness (J/cm^2)	Chip fragmentation
Example 1	Inventive Steel 1	1090	0.5	841	67	good
Example 2	Inventive Steel 2	1090	0.5	789	80	good
Example 3	Inventive Steel 3	1090	0.5	703	76	good
Example 4	Inventive Steel 4	1090	0.5	868	80	good
Example 5	Inventive Steel 5	1090	0.5	791	72	good
Example 6	Inventive Steel 6	1090	0.5	761	69	good
Example 7	Inventive Steel 7	1090	0.5	826	66	good
Comparative Example 1	**Comparative Steel 1**	1090	0.5	**535**	93	fair
Comparative Example 2	**Comparative Steel 2**	1090	0.5	956	61	**poor**

(continued)

Category	Steel type	Heating temperature of steel piece (°C)	Average cooling rate to 400°C (°C/s)	Tensile strength (MPa)	Room-temperature impact toughness (J/cm^2)	Chip fragmentation
Comparative Example 3	**Comparative Steel 3**	1090	0.5	**611**	111	fair
Comparative Example 4	**Comparative Steel 4**	1090	0.5	716	**59**	**poor**
Comparative Example 5	Inventive Steel 1	**1150**	0.5	790	**55**	fair
Comparative Example 6	Inventive Steel 2	1090	**10.0**	826	**54**	**poor**
Comparative Example 7	Inventive Steel 3	1090	**0.05**	**690**	76	fair

[0060] As shown in Tables 1 and 2, the steel rod wires of Examples 1 to 7 satisfying all of the chemical composition, the relational expressions, and the manufacturing conditions provided in the present disclosure, had tensile strengths of 700 MPa or more, impact roughnesses of 60 J/cm^2 or more, and good machinability. On the contrary, it was confirmed that the steel rod wires of Comparative Examples 1 to 7 not satisfying at least one of the above-described conditions had one or more poor property among tensile strength, machinability, and impact toughness. Specifically, Comparative Example 1 having a low C content could not satisfy the suggested tensile strength or 700 MPa or more, and Comparative Example 2 having an excess of Si and a S/Ca value of only 8 had poor machinability. Comparative Example 3 not satisfying the suggested Mn content and Relational Expression 3 could not obtain sufficient strength. Comparative Example 4 including an excess of Ti and not satisfying Relational Expression 1 had insufficient toughness. Although Comparative Examples 5 to 7 satisfied the chemical composition suggested by the present disclosure, the heating temperatures were out of the suggested range or the average cooling rates were not satisfied while cooling to 400°C, and thus toughness and tensile strength were out of the target vales.

[0061] While the present disclosure has been particularly described with reference to exemplary embodiments, it should be understood by those of skilled in the art that various changes in form and details may be made without departing from the spirit and scope of the present disclosure.

[Industrial Applicability]

[0062] According to the present disclosure, a non-quenched and tempered steel rod wire with both improved machinability and toughness may be provided even when heat treatment is omitted, and therefore the present disclosure has industrial applicability.

Claims

1. A non-quenched and tempered steel rod wire 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, 0.01% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.01% to 0.02% of Ti, 0.0005% to 0.002% of Ca, 0.007% to 0.02% of N, and the remainder being Fe and inevitable impurities, and

   including ferrite and pearlite as microstructures,
   wherein the steel rod wire satisfies Relational Expression 1 below:

   $$[\text{Relational Expression 1}]\ 2 \leq (\text{Al}+\text{Ti})/\text{N} \leq 5.$$

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

$$[\text{Relational Expression 2}]\ 10 \leq S/Ca \leq 70.$$

3. The non-quenched and tempered steel rod wire according to any one of claim 1 to claim 2, wherein the non-quenched and tempered steel rod wire satisfies Relational Expression 3 below:

$700 \leq 300 + 903 \times C + 95 \times Si + 154 \times Mn - 2303 \times S.$ [Relational Expression 3]

4. The non-quenched and tempered steel rod wire according to any one of claim 1 to claim 3, wherein an average inter-layer spacing between ferrite and pearlite is 10.0 μm to 15.0 μm.

5. The non-quenched and tempered steel rod wire according to any one of claim 1 to claim 4, wherein a thickness of the ferrite is 5.0 μm to 10.0 μm.

6. The non-quenched and tempered steel rod wire according to any one of claim 1 to claim 5, wherein an aspect ratio of the ferrite is 4 or less.

7. The non-quenched and tempered steel rod wire according to any one of claim 1 to claim 6, wherein a tensile strength is 700 MPa or more.

8. The non-quenched and tempered steel rod wire according to any one of claim 1 to claim 7, wherein a yield strength is 350 MPa to 450 MPa.

9. The non-quenched and tempered steel rod wire according to any one of claim 1 to claim 8, wherein a yield ratio is 0.45 to 0.65.

10. The non-quenched and tempered steel rod wire according to any one of claim 1 to claim 9, wherein an impact toughness is 60 J/cm^2.

11. The non-quenched and tempered steel rod wire according to any one of claim 1 to claim 10, wherein a product of tensile strength and impact toughness is 30000 to 60000.

12. A method for manufacturing a non-quenched and tempered steel rod wire 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, 0.01% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.01% to 0.02% of Ti, 0.0005% to 0.002% of Ca, 0.007% to 0.02% of N, and the remainder being Fe and inevitable impurities, and including ferrite and pearlite as microstructures, in a temperature range of 950°C to 1120°C;
finish rolling the reheated steel piece into a steel rod wire at a temperature of 750°C to 850°C; and
winding and cooling the steel rod wire,
wherein the cooling performed after the winding includes a process of cooling the steel rod wire to 400°C at an average cooling rate of 0.1°C/s to 5.0°C/s, and the steel rod wire satisfies Relational Expression 1 below:

$$[\text{Relational Expression 1}]\ 2 \leq (Al+Ti)/N \leq 5.$$

13. The method according to claim 12, wherein the steel rod wire satisfies Relational Expression 2 below:

$$[\text{Relational Expression 2}]\ 10 \leq S/Ca \leq 70.$$

14. The method according to any one of claim 12 to claim 13, wherein the steel rod wire satisfies Relational Expression 3 below:

$700 \leq 300 + 903 \times C + 95 \times Si + 154 \times Mn - 2303 \times S.$ [Relational Expression 3]

15. The method according to any one of claim 12 to claim 14, wherein the steel rod wire has an average inter-layer spacing between ferrite and pearlite of 10.0 μm to 15.0 μm.

16. The method according to any one of claim 12 to claim 15, wherein the ferrite of the steel rod wire has a thickness of 5.0 μm to 10.0 μm.

17. The method according to any one of claim 12 to claim 16, wherein the ferrite of the steel rod wire has an aspect ratio of 4 or less.

18. The method according to any one of claim 12 to claim 17, wherein a tensile strength of the steel rod wire is 700 MPa or more.

19. The method according to any one of claim 12 to claim 18, wherein a yield strength of the steel rod wire is 350 MPa to 450 MPa.

20. The method according to any one of claim 12 to claim 19, wherein a yield ratio of the steel rod wire is 0.45 to 0.65.

21. The method according to any one of claim 12 to claim 20, wherein an impact toughness of the steel rod wire is 60 J/cm^2 or more.

22. The method according to any one of claim 12 to claim 21, wherein a product of tensile strength and impact toughness of the steel rod wire is 30000 to 60000.

INTERNATIONAL SEARCH REPORT

International application No. **PCT/KR2023/007282**

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/28(2006.01)i; **C22C 38/00**(2006.01)i; **B21B 1/16**(2006.01)i; **B21C 47/02**(2006.01)i; **C21D 9/573**(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 38/28(2006.01); B21B 1/16(2006.01); C21D 8/06(2006.01); C22C 38/00(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), 선재(wire rod), 알루미늄(Al), 티타늄(Ti), 질소(N), 인성(toughness)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	KR 10-2020-0062439 A (POSCO) 04 June 2020 (2020-06-04) See paragraph [0071], claims 1-2, 8 and 10-12, tables 2-3 and figure 1.	1-22
Y	JP 06-073490 A (AICHI STEEL WORKS LTD.) 15 March 1994 (1994-03-15) See paragraph [0160] and claim 3.	1-22
A	JP 09-025541 A (SUMITOMO METAL IND. LTD.) 28 January 1997 (1997-01-28) See claim 1.	1-22
A	KR 10-2016-0068120 A (POSCO) 15 June 2016 (2016-06-15) See claims 1-2 and 5-6.	1-22
A	KR 10-2000-0025695 A (POHANG IRON & STEEL CO., LTD.) 06 May 2000 (2000-05-06) See claim 1.	1-22

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

* Special categories of cited documents:

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

Date of the actual completion of the international search	Date of mailing of the international search report
07 September 2023	**07 September 2023**

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2023/007282

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JP 09-025541 A	28 January 1997	None	
KR 10-2016-0068120 A	15 June 2016	CN 105671458 A	15 June 2016
		CN 105671458 B	20 April 2018
		KR 10-1674750 B1	10 November 2016
KR 10-2000-0025695 A	06 May 2000	KR 10-0398378 B1	18 December 2003

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