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

(57) Provided are a non-quenched and non-tempered steel wire rod with improved machinability and impact toughness and a method for manufacturing the same. The non-quenched and non-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, 0.01% 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 balance of Fe and inevitable impurities, and includes ferrite and pearlite as a microstructure, wherein Relational Expression 1 below is satisfied and an area fraction of MnS satisfies a range of 0.10% to 0.60%.

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

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Description

[Technical Field]

[0001] The present disclosure relates to a non-quenched and non-tempered steel wire rod with improved machinability and impact toughness and a method for manufacturing the same, and more particularly, to a non-quenched and non-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 non-tempered steels. Therefore, non-quenched and non-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 non-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 non-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] The present disclosure relates to a non-quenched and non-tempered steel wire rod with excellent 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 non-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, 0.01% 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 balance of Fe and inevitable impurities, and includes ferrite and pearlite as a microstructure, wherein Relational Expression 1 below is satisfied and an area fraction of MnS satisfies a range of 0.10 to 0.60%.

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

[0005] According to an embodiment of the present disclosure, in the non-quenched and non-tempered steel wire rod with improved machinability and impact toughness, a number density of MnS may be 70 ea/mm^2 or more and an aspect ratio of MnS may be 40 or less.

[0006] According to an embodiment of the present disclosure, the non-quenched and non-tempered steel wire rod with improved machinability and impact toughness may have a tensile strength of 700 MPa or more, a yield strength of 350 to 500 MPa, and a yield ratio of 0.45 to 0.65.

[0007] According to an embodiment of the present disclosure, the non-quenched and non-tempered steel wire rod with improved machinability and impact toughness may have an impact toughness of 60 J/cm^2 or more and a tensile strength x impact toughness value of 45000 MPa·J/cm^2 or more.

[0008] A method for manufacturing a non-quenched and non-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, 0.01% 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 balance of Fe and inevitable impurities, and including ferrite and pearlite as a microstructure in a temperature range of 950 to 1120°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 process of cooling to 400°C at an average cooling rate of 0.1 to 5.0°C/s, wherein the steel wire rod includes ferrite and pearlite as a microstructure, Relational Expression 1 is satisfied, and an area fraction of MnS is 0.10 to 0.60%.

[Advantageous Effects]

[0009] In the non-quenched and non-tempered steel wire rod 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 wire rod may be applied to materials for automobiles or mechanical parts that require both machinability and toughness.

[Best Mode]

[0010] A non-quenched and non-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, 0.01% 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 balance of Fe and inevitable impurities, and includes ferrite and pearlite as a microstructure, wherein Relational Expression 1 below is satisfied and an area fraction of MnS satisfies a range of 0.10 to 0.60%.

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

[Modes of the Invention]

[0011] 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.

[0012] 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 toughness may be obtained by appropriately controlling a composition of alloying elements and a microstructure of the steel wire rod without an additional heat treatment, thereby completing the present disclosure.

[0013] A non-quenched and non-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, 0.01% 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 balance of Fe and inevitable impurities, and includes ferrite and pearlite as a microstructure, wherein Relational Expression 1 below is satisfied and an area fraction of MnS is 0.10 to 0.60%.

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

[0014] 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.

[0015] The content of C is 0.3% to 0.5%.

[0016] 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%.

[0017] The content of Si is 0.4% to 0.9%.

[0018] 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%.

[0019] The content of Mn is 0.5% to 1.2%.

[0020] 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%.

[0021] The content of Cr is 0.1% to 0.3%.

[0022] 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 a steel more than necessary, reduces an amount of a solid solution of C by precipitating carbides in a steel, and contributes to reduction in dynamic deformation aging caused by the 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%.

[0023] The content of P is 0.02% or less.

[0024] Phosphorus (P), as an impurity inevitably contained in steels, is segregated into grain boundaries as a major causative element of 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.

[0025] The content of S is 0.01% to 0.05%.

[0026] Sulfur (S), as a major causative element of significant deterioration in ductility as being segregated 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 a 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.

[0027] The content of sol.Al is 0.01% to 0.05%.

[0028] The sol.Al is an element effective as a deoxidizer. The sol.Al may be contained in an amount of 0.01% or more 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 produced during casting process. Therefore, the upper limit of the Al content may be controlled to 0.05% in the present disclosure.

[0029] The content of Ti is 0.01% to 0.02%.

[0030] 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 for inhibiting 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.

[0031] The content of Ca is 0.0005% to 0.002%.

[0032] 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 formation, to inhibit elongation of MnS while rolling the steel wire rod 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%

[0033] The content of N is 0.007% to 0.02%.

[0034] 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 wire rod. Therefore, the upper limit of the N content may be controlled to 0.02% in the present disclosure.

[0035] The remaining component of the non-quenched and non-tempered steel wire rod of the present disclosure is iron (Fe). However, the non-quenched and non-tempered steel wire rod may include other impurities incorporated during common industrial manufacturing processes of steels. Types and contents of the impurities are not specifically mentioned in the present disclosure, as they are known to any person skilled in the art of manufacturing.

[0036] The non-quenched and non-tempered steel wire rod according to an embodiment of the present disclosure may satisfy Relational Expression 1 below. In Relational Expression 1, [S] and [Mn] respectively represent contents (wt%) of the elements.

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

[0037] 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 medium-carbon non-quenched and non-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, preferably 30 to 60, in the present disclosure.
[0038] In addition, in the non-quenched and non-tempered steel material according to an embodiment of the present disclosure, an area fraction of MnS may be 0.10 to 0.60%, preferably 0.15 to 0.50%, and more preferably 0.15 to 0.45%.
[0039] In addition, in the non-quenched and non-tempered steel material according to an embodiment of the present disclosure, a number density of MnS may be 70 ea/mm^2 or more, preferably 80 ea/mm^2 or more, and more preferably 90 ea/mm^2 or more. As the density of MnS increases, MnS serves as a stress concentration source during cutting, to reduce cutting resistance, thereby improving machinability. To this end, the density of MnS needs to be at least 70 ea/mm^2.
[0040] In addition, in the non-quenched and non-tempered steel material according to an embodiment of the present disclosure, the aspect ratio of MnS may be 40 or less, preferably 30 or less, and more preferably 20 or less. In this case, when the aspect ratio of MnS is greater than 40, impact toughness may rapidly decrease.
[0041] In addition, the non-quenched and non-tempered steel wire rod according to an embodiment of the present disclosure may have a tensile strength of 700 MPa or more.
[0042] In addition, the non-quenched and non-tempered steel wire rod according to an embodiment of the present disclosure may have a yield strength of 350 to 500 MPa.
[0043] In addition, the non-quenched and non-tempered steel wire rod according to an embodiment of the present disclosure may have a yield ratio of 0.45 to 0.65.
[0044] In addition, the non-quenched and non-tempered steel wire rod according to an embodiment of the present disclosure may have an impact toughness of 60 J/cm^2 or more.
[0045] In addition, the non-quenched and non-tempered steel wire rod according to an embodiment of the present disclosure may have a tensile strength x impact toughness value of 45000 MPa·J/cm^2 or more.
[0046] Hereinafter, a method for manufacturing a non-quenched and non-tempered steel wire rod according to an embodiment of the present disclosure will be described.
[0047] The non-quenched and non-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, 0.01% 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 balance of Fe and inevitable impurities, and including ferrite and pearlite as a microstructure in a temperature range of 950 to 1120°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 process of cooling to 400°C at an average cooling rate of 0.1 to 5.0°C/s, wherein the steel wire rod includes ferrite and pearlite as a microstructure, Relational Expression 1 is satisfied, and an area fraction of MnS is 0.10 to 0.60%.

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

[0048] Hereinafter, each process of the manufacturing method will be described in more detail.
[0049] First, a bloom satisfying the above-described composition of alloying elements is heated and rolled into a billet.

Reheating Process

[0050] The reheating process, as a step of reheating the rolled billet, is a process for lowering a rolling load while rolling the steel wire rod. 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 process. On the contrary, at a reheating temperature above 1,120°C, all AlN finely formed in the steel piece may form a solid solution again during heating, thereby significantly decreasing a grain refinement effect.

Process of Rolling Steel Wire Rod

[0051] In the process of rolling the steel wire rod, the reheated pieces of the steel are hot-rolled into a steel wire rod.
[0052] 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

[0053] 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 a 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 a surface layer during cooling cannot be recovered due to recuperated 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 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

[0054] The wound steel wire rod 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, so that toughness and machinability may deteriorate.

{Examples}

[0055] 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. Subsequently, the billet was heated under the temperature conditions shown in Table 2 below for 90 minutes, finish-rolled at 800°C, wound at 780°C, and cooled under the temperature conditions of Table 2 below into a steel wire rod having a diameter of 26 mm. Steel wire rods including compositions of Inventive Steels 1 to 7 and Comparative Steels 1 to 6 were manufactured (Table 1), and machinability, tensile strength, and impact toughness of specimens of the steel wire rods were measured.

[0056] Here, room-temperature tensile strength was measured at the center of the specimens of the non-quenched and non-tempered steels at 25°C, and room-temperature impact toughness was measured at 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.

[0057] 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 the degree of tool wear 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. As a cutting tool, a Cermet tool with a chip breaker was used. A wear depth of the tool was obtained by measuring depths from the surface of flank wear after continuously processing 300 parts having the above-described shape. A wear depth greater than 0.2 mm was evaluated as poor, and a wear depth of 0.2 mm or less was evaluated as good.

[0058] In addition, area fractions of MnS, number densities of MnS, and aspect ratios of MnS were evaluated by obtaining 20 images of L cross-sections of each wire rod using an optical microscope at a magnification of 200x and analyzing the images by image analysis software.

[Table 1]

Category	Chemical composition of alloying elements (wt%)										Relational Expression (1)
	C	Si	Mn	P	S	Al	Cr	Ti	Ca	N	
Inventive Steel 1	0.45	0.59	1.06	0.0055	0.026	0.047	0.22	0.0189	0.0013	0.0185	40.2
Inventive Steel 2	0.31	0.53	1.15	0.0156	0.032	0.046	0.16	0.0155	0.0017	0.0074	36.3

(continued)

Category	Chemical composition of alloying elements (wt%)										Relational Expression (1)
	C	Si	Mn	P	S	Al	Cr	Ti	Ca	N	
Inventive Steel 3	0.46	0.82	1.14	0.0104	0.036	0.014	0.15	0.0140	0.0008	0.0187	31.8
Inventive Steel 4	0.49	0.43	1.14	0.0200	0.030	0.044	0.30	0.0112	0.0009	0.0130	38.5
Inventive Steel 5	0.38	0.69	0.95	0.0178	0.018	0.017	0.18	0.0171	0.0014	0.0104	53.7
Inventive Steel 6	0.48	0.58	0.70	0.0137	0.021	0.011	0.13	0.0113	0.0007	0.0133	33.5
Inventive Steel 7	0.35	0.67	1.17	0.0160	0.027	0.050	0.27	0.0134	0.0013	0.0138	42.9
Comparative Steel 1	**0.65**	0.75	0.89	0.0092	0.016	0.027	0.14	0.0137	0.0014	0.0100	54.3
Comparative Steel 2	0.30	**1.21**	1.07	0.0123	0.049	0.050	0.26	0.0155	0.0014	0.0195	21.7
Comparative Steel 3	0.44	0.63	**1.31**	0.0069	0.033	0.032	0.15	0.0199	0.0014	0.0127	39.2
Comparative Steel 4	0.33	0.90	0.88	0.0058	0.041	0.038	0.24	**0.0005**	0.0017	0.0191	21.5
Comparative Steel 5	0.31	0.81	0.66	0.0184	0.017	0.027	0.25	0.0143	**0.0002**	**0.0052**	39.5
Comparative Steel 6	0.40	0.56	1.09	0.0177	0.0109	0.0465	0.22	0.0103	0.0013	0.0097	**100.0**

[Table 2]

Category	Steel type	Heating temperature (°C)	Average cooling rate to 400°C (°C/s)	Area fraction of MnS (%)	MnS density (ea/mm^2)	Aspect ratio of MnS
Example 1	Inventive Steel 1	1090	0.5	0.23	117	28
Example 2	Inventive Steel 2	1090	0.5	0.36	141	19
Example 3	Inventive Steel 3	1090	0.5	0.41	160	37
Example 4	Inventive Steel 4	1090	0.5	0.27	132	33
Example 5	Inventive Steel 5	1090	0.5	0.18	82	22
Example 6	Inventive Steel 6	1090	0.5	0.20	93	36
Example 7	Inventive Steel 7	1090	0.5	0.29	121	28
Comparative Example 1	Comparative Steel 1	1090	0.5	0.12	73	27
Comparative Example 2	Comparative Steel 2	1090	0.5	0.45	220	24
Comparative Example 3	Comparative Steel 3	1090	0.5	0.30	148	23
Comparative Example 4	Comparative Steel 4	1090	0.5	0.41	182	21
Comparative Example 5	Comparative Steel 5	1090	0.5	0.18	74	**48**

(continued)

Category	Steel type	Heating temperat ure (°C)	Average cooling rate to 400°C (°C/s)	Area fraction of MnS (%)	MnS density (ea/mm^2)	Aspect ratio of MnS
Comparative Example 6	Comparative Steel 6	1090	0.5	**0.08**	**48**	37
Comparative Example 7	Inventive Steel 1	**1150**	0.5	0.26	117	33
Comparative Example 8	Inventive Steel 2	1090	**10.0**	0.34	141	17
Comparative Example 9	Inventive Steel 3	1090	**0.05**	0.41	160	23

[Table 3]

Category	Steel type	Tensile strength (MPa)	Yield strength (MPa)	Yiel d ratio	Toug hnes s (J/c m^2)	Tensile strength x impact toughness (MPa·J/c m^2)	Machin ability (tool wear)
Example 1	Inventive Steel 1	865	418	0.48	75	62486	good
Example 2	Inventive Steel 2	734	400	0.54	86	64969	good
Example 3	Inventive Steel 3	886	403	0.45	85	54179	good
Example 4	Inventive Steel 4	891	492	0.55	63	56033	good
Example 5	Inventive Steel 5	814	460	0.57	72	62798	good
Example 6	Inventive Steel 6	848	413	0.49	72	51875	good
Example 7	Inventive Steel 7	797	410	0.51	89	60722	good
Comparative Example 1	Comparative Steel 1	930	498	0.54	61	56730	**poor**
Comparative Example 2	Comparative Steel 2	723	394	0.55	**58**	**41934**	good
Comparative Example 3	Comparative Steel 3	861	459	0.53	**55**	47355	good
Comparative Example 4	Comparative Steel 4	710	386	0.54	**58**	**41180**	good
Comparative Example 5	Comparative Steel 5	707	394	0.56	**52**	**36764**	good
Comparative Example 6	Comparative Steel 6	820	450	0.55	65	53300	**poor**
Comparative Example 7	Inventive Steel 1	738	424	0.57	**57**	**42066**	good
Comparative Example 8	Inventive Steel 2	870	432	0.50	**48**	**41760**	**poor**
Comparative Example 9	Inventive Steel 3	**688**	390	0.57	85	58711	good

[0059] As shown in Tables 1 to 3, the steel wire rods of Examples 1 to 7 satisfying all of the chemical composition, the relational expression, and the area fraction of MnS, the number density, the aspect ratio, and the manufacturing conditions provided in the present disclosure, satisfied a tensile strength of 700 MPa or more, a yield strength of 350 to 500 MPa, a yield ratio of 0.45 to 0.65, a tensile strength x impact toughness value of 45000 MPa·J/cm^2 or more, an impact toughness of 60 J/cm^2 or more, and good machinability.

[0060] On the contrary, the steel wire rods of Comparative Examples 1 to 9 which do not satisfy one or more conditions provided in the present disclosure had at least one poor property selected from tensile strength, impact toughness, tensile strength x impact toughness value, and machinability.

[0061] Specifically, Comparative Example 1 not satisfying the C content range suggested by the present disclosure exhibited poor tool wear due to high strength, and Comparative Examples 2 and 3 exhibited lower impact toughness due to excessive amounts of Si and Mn. In addition, Comparative Example 4 exhibited poor impact toughness due to insufficient grain refinement effect because the Ti content is insufficient. Comparative Example 5 exhibited reduced impact toughness due to a higher aspect ratio of MnS, and Comparative Example 6 exhibited poor tool wear due to insufficient area faction and density because Relational Expression (1) was not satisfied. Although Comparative Examples 7 to 9 satisfied the chemical composition, toughness was poor or target strength was not satisfied because the heating temperature and the cooling rate were out of the suggested ranges.

[0062] 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]

[0063] According to the present disclosure, a non-quenched and non-tempered steel wire rod having both machinability and impact toughness and a method for manufacturing the same may be provided without additional heat treatment, and therefore the present disclosure has industrial applicability.

Claims

1. A non-quenched and non-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, 0.01% 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 balance of Fe and inevitable impurities, and including ferrite and pearlite as a microstructure, wherein Relational Expression 1 below is satisfied and an area fraction of MnS satisfies a range of 0.10% to 0.60%:

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

2. The non-quenched and non-tempered steel wire rod according to claim 1, wherein a number density of MnS is 70 ea/mm^2 or more.

3. The non-quenched and non-tempered steel wire rod according to claim 1, wherein an aspect ratio of MnS is 40 or less.

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

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

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

7. The non-quenched and non-tempered steel wire rod according to claim 1, wherein an impact toughness is 60 J/cm^2 or more.

8. The non-quenched and non-tempered steel wire rod according to claim 1, wherein a tensile strength x impact toughness value is 45000 MPa·J/cm^2 or more.

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

reheating a steel piece 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 balance of Fe and inevitable impurities, and including ferrite and pearlite as a microstructure in a temperature range of 950°C to 1120°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 process of cooling to 400°C at an average cooling rate of 0.1°C/s to 5.0°C/s, wherein the steel wire rod includes ferrite and pearlite as a microstructure, Relational Expression 1 is satisfied, and an area fraction of MnS is 0.10% to 0.60%:

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

10. The method according to claim 9, wherein a number density of MnS is 70 ea/mm^2 or more.

11. The method according to claim 9, wherein an aspect ratio of MnS is 40 or less.

12. The method according to claim 9, wherein a winding temperature is 750°C to 850°C.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2023/007444

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); B21J 5/00(2006.01); C21D 8/06(2006.01); C22C 38/00(2006.01); C22C 38/06(2006.01); C22C 38/28(2006.01); C22C 38/38(2006.01); C22C 38/60(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 선재(non-heat treated wire rod), 황화 망가니즈(manganese sulfide), 탄소(carbon), 페라이트(ferrite), 및 펄라이트(pearlite)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 2002-226939 A (DAIDO STEEL CO., LTD.) 14 August 2002 (2002-08-14) See paragraphs [0007]-[0024]; claim 1; and table 2.	1,2,7 3-6,8-12
Y	KR 10-2012-0049405 A (NIPPON STEEL CORPORATION) 16 May 2012 (2012-05-16) See paragraphs [0009]-[0014] and [0019]-[0027] and table 2.	3-6,8,11
Y	KR 10-1630978 B1 (POSCO) 16 June 2016 (2016-06-16) See paragraphs [0012] and [0057]-[0060].	9-12
A	JP 2008-231544 A (SUMITOMO METAL IND LTD.) 02 October 2008 (2008-10-02) See paragraph [0026].	1-12
A	US 2010-0183473 A1 (TERAMOTO, Shinya et al.) 22 July 2010 (2010-07-22) See paragraphs [0029]-[0044].	1-12

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

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Date of the actual completion of the international search	Date of mailing of the international search report
14 September 2023	**15 September 2023**

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
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Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2002-226939 A	14 August 2002	JP 4556334 B2	06 October 2010
		US 2002-0139451 A1	03 October 2002
		US 6599469 B2	29 July 2003
KR 10-2012-0049405 A	16 May 2012	CA 2681788 A1	03 September 2009
		CN 101652493 A	17 February 2010
		CN 101652493 B	23 November 2011
		EP 2246451 A1	03 November 2010
		EP 2246451 B1	09 October 2013
		JP 5251872 B2	31 July 2013
		KR 10-1177542 B1	28 August 2012
		KR 10-2009-0109548 A	20 October 2009
		RU 2009136184 A	10 April 2011
		RU 2431694 C2	20 October 2011
		TW 200936784 A	01 September 2009
		TW I470089 B	21 January 2015
		US 2010-0143180 A1	10 June 2010
		US 2014-0219858 A1	07 August 2014
		US 8715428 B2	06 May 2014
		US 9255314 B2	09 February 2016
		WO 2009-107282 A1	03 September 2009
KR 10-1630978 B1	16 June 2016	None	
JP 2008-231544 A	02 October 2008	JP 4793298 B2	12 October 2011
US 2010-0183473 A1	22 July 2010	CN 101568661 A	28 October 2009
		CN 101568661 B	02 May 2012
		EP 2204463 A1	07 July 2010
		EP 2204463 B1	01 May 2019
		EP 2204463 B8	14 August 2019
		JP 5079788 B2	21 November 2012
		KR 10-1125404 B1	27 March 2012
		KR 10-2009-0078806 A	20 July 2009
		RU 2439189 C1	10 January 2012
		TW 200932923 A	01 August 2009
		TW I393790 B	21 April 2013
		US 2016-0251743 A1	01 September 2016
		US 9376738 B2	28 June 2016
		US 9487848 B2	08 November 2016
		WO 2009-057731 A1	07 May 2009

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