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(54) NON-QUENCHED AND TEMPERED STEEL ROD WIRE 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 impact toughness and method for manufacturing same. The non-quenched and tempered steel rod wire 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 balance being Fe and inevitable impurities, wherein a microstructure includes ferrite and pearlite, and Relational Expression 1 below is satisfied:

$$\text{[Relational Expression1] } [N]-[Al]/1.93 \leq 0.009.$$

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Description

[Technical Field]

[0001] The present disclosure relates to a non-quenched and tempered steel rod wire with excellent 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 steels. 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 having impact toughness and providing cutting tools with abrasion resistance by adjusting a microstructure, for example, refining a structure via AlN grain boundary peening and low-temperature rolling or by obtaining a sufficient fraction of ferrite, which is a soft phase, in order to improve impact toughness inferior to that of conventional quenched and tempered steels, and a method for manufacturing the 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, 0.015% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.007% to 0.020% of N, and the balance being Fe and inevitable impurities, wherein a microstructure includes ferrite and pearlite, and Relational Expression 1 below is satisfied.

$$[\text{Relational Expression 1}]\ [N]-[Al]/1.93 \leq 0.009$$

[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, 0.015% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.007% to 0.020% of N, and the balance being Fe and inevitable impurities at a temperature of 950°C to 1100°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 more than 0.1°C/s but not more than 5.0°C/s, and the steel rod wire satisfies the Relational Expression 1.

[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, Al combines with N to form an AlN nitride, which inhibits the growth of grain boundaries during heating and refines grains, thereby improving impact toughness. In addition, impact toughness is further improved by adjusting an area fraction of ferrite to 20% to 40% in a region from the center to a quarter or more of the diameter of the steel rod wire from the surface. Deterioration of impact toughness may be minimized and machinability, particularly, abrasion resistance of cutting tools, may be obtained by decreasing the size of MnS, which improves machinability but may deteriorate impact toughness. Therefore, the steel rod wire may be applied to materials for automobiles or mechanical parts that require machinability and impact toughness even after omitting heat treatment.

[Best Mode]

[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, 0.015% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.007% to 0.02% of N, and the balance being Fe and inevitable impurities, wherein a microstructure includes ferrite and pearlite, and Relational Expression 1 below is satisfied.

[Relational Expression 1] $[N]-[Al]/1.93 \leq 0.009$.

[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 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, 0.015% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.007% to 0.02% of N, and the balance being Fe and inevitable impurities, wherein a microstructure includes ferrite and pearlite, and Relational Expression 1 below is satisfied.

[Relational Expression 1] $[N]-[Al]/1.93 \leq 0.009$

[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), 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 resulting in deterioration of cold workability, and 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, and therefore, the upper limit of the Mn content may be controlled to 1.2%.

[0018] The content of P is 0.02% or less.

[0019] 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.

[0020] The content of S is 0.01% to 0.05%.

[0021] Sulfur (S), as a major causative element of segregation into grain boundaries resulting in significant deterioration in ductility and formation of an emulsion in a steel impairing 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.

[0022] The content of sol.Al is 0.015% to 0.05%.

[0023] 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 casting process due to Al oxides. Therefore, the upper limit of the Al content may be controlled to 0.05% in the present disclosure.

[0024] The content of Cr is 0.1% to 0.3%.

[0025] 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 a solid solution of C by precipitating carbides, 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%.

[0026] The content of N is 0.007% to 0.02%.

[0027] 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 rod wire. Therefore, the upper limit of the N content may be controlled to 0.02% in the present disclosure.

[0028] 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.

[0029] The non-quenched and tempered steel rod wire according to an embodiment of the present disclosure may satisfy Relational Expressions 1 and 2. In Relational Expressions 1 and 2, [Al], [N], [C], [S], [Mn], and [Si] respectively represent contents (wt%) of the elements.

[Relational Expression 1] (impact toughness)

$$[N]-[Al]/1.93 \leq 0.009$$

[0030] Relational Expression 1 is an expression related to toughness. According to the present disclosure, AlN is formed by adding high contents of N and Al. Because fine AlN precipitates in a steel inhibit the growth of crystal grains, particles are refined to improve impact toughness of the non-quenched and tempered steel rod wire according to the present disclosure. In order to express the above-described effect, it is preferable to control a [N]-[Al]/1.93 ratio to 0.009 or less. At a [N]-[Al]/1.93 ratio exceeding 0.009, a significant amount of N added in a state where Al is insufficient is present in a steel without combining with Al, and thus impact toughness may deteriorate.

[Relational Expression 2] $-23[C]+[Si](5-2[Si])-4[Mn]+104[S]+3 \geq 0$ (machinability)

[0031] Relational Expression 2 is an expression related to tool wear among machinability. In general, addition of S causes formation of MnS that serves as a stress concentrator during a cutting process to deteriorate cutting resistance and performs lubrication to improve lifespan of tools. However, because tool wear is accelerated in the case where hardness increases due to added alloying elements, they should be considered together. Relational Expression 2 reflects these effects, complexly, and at a value of 0 or more, tool wear is not serious.

[0032] The non-quenched and tempered steel rod wire according to an embodiment of the present disclosure includes ferrite and pearlite as microstructures, wherein an area fraction of ferrite, measured in a region from the center to a quarter or more of the diameter of the steel rod wire from the surface, satisfies a range of 20 to 40%.

[0033] In the non-quenched and tempered steel rod wire according to an embodiment of the present disclosure, an area fraction of the formed AlN may be 0.03% or more.

[0034] In the non-quenched and tempered steel rod wire according to an embodiment of the present disclosure, a size of the formed AlN may be 150 nm or less.

[0035] In addition, in the non-quenched and tempered steel rod wire according to an embodiment of the present disclosure, the number of carbonitrides having an average equivalent circular diameter of 100 nm or less per unit area may be 2 ea./μm^2 or more.

[0036] In addition, the non-quenched and tempered steel material according to the present disclosure may have a tensile strength of 700 MPa or more.

[0037] In addition, the non-quenched and tempered steel material according to the present disclosure may have a yield strength of 350 to 450 MPa.

[0038] In addition, the non-quenched and tempered steel material according to the present disclosure may have a yield ratio of 0.45 to 0.65.

[0039] In addition, the non-quenched and tempered steel material according to the present disclosure may have an impact toughness of 60 J/cm^2 or more.

[0040] In addition, the non-quenched and tempered steel material according to the present disclosure may have a product of tensile strength and impact toughness of 30000 to 60000.

[0041] Hereinafter, a method for manufacturing a non-quenched and tempered steel rod wire according to an embodiment of the present disclosure will be described.

[0042] The non-quenched and tempered steel rod wire with improved machinability and impact toughness according to the present disclosure may be manufactured in various methods, and the manufacturing method therefor is not particularly limited. However, the steel rod wire may be manufactured according to the following method.

[0043] 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, 0.015% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.007% to 0.020% of N, and the balance being Fe and inevitable impurities; hot rolling the reheated steel piece into a steel rod wire; and winding and cooling the steel rod wire,

[0044] wherein the cooling performed after the winding includes a process of cooling the steel rod wire to 400°C at an average cooling rate more than 0.1 °C/s but not more than 5.0°C/s, and the steel rod wire satisfies Relational Expression 1 below.

[Relational Expression 1] $[N]-[Al]/1.93 \leq 0.009$

[0045] Hereinafter, each process of the manufacturing method will be described in more detail.

[0046] First, a bloom satisfying the above-described composition of alloying elements is heated and rolled into a billet.

Reheating Process

[0047] The reheating process, as a process 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 1100°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 pieces of the steel may form a solid solution again during heating, so that the area fraction of AlN changed to be less than 0.03%, thereby significantly decreasing the grain refinement effect.

Process of Rolling Steel Rod Wire

[0048] In the process of rolling the steel rod wire, the reheated steel pieces are hot-rolled into a steel rod wire.

[0049] 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 it may be difficult to obtain a high toughness desired in the present disclosure.

Winding Process

[0050] A process of winding the steel rod wire manufactured as described above into a coil shape 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 the winding temperature or may be wound without the 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 restored due to double rows, and tempered martensite may be 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

[0051] The wound steel rod wire may be cooled, and in this case, the cooling process may be performed to 400°C at an average cooling rate more than 0.1°C/s but not more than 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 formed and thus toughness and machinability may deteriorate.

{Examples}

[0052] 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 7 were manufactured (Table 1) and tensile strength, impact toughness, wear depth of cutting tool, and area fractions of ferrite and AlN of the specimens of the steel rod wires were measured and shown in Table 2 below.

[0053] 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 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.

[0054] In addition, in order to evaluate machinability, the steel rod wire having a diameter of 26 mm was processed with a reduction rate of 14.8% into cold drawn bars (CD-Bars) with a diameter of 24 mm. The degree of tool wear was evaluated by using a CNC lathe. After the CD-Bar with a diameter of 24 mm was subject to a turning operation to a diameter of 15 mm and a length of 20 mm, the degree of tool wear was evaluated. 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, and a Cermet tool with a chip breaker was used as the cutting tool. After continuously processing 300 parts having the above-described shape, a tool wear depth was evaluated by measuring a depth of flank wear, and a depth more than 0.2 mm was evaluated as poor and a depth not more than 0.2 mm was evaluated as good. In order to measure and quantify an area fraction of extremely fine AlN with a size of 100 nm or less, transmission electron microscope specimens were prepared and observed at a magnification of 100,000x using the replica method, and then an arithmetic mean of the AlN area fraction was obtained from 50 images using image analysis software.

[Table 1]

Category	Chemical composition of alloying elements (wt%)								Relational Expression	
	C	Si	Mn	P	S	Al	Cr	N	(1)	(2)
Inventive Steel 1	0.37	0.62	1.06	0.0132	0.036	0.035	0.11	0.0096	-0.0084	4.1
Inventive Steel 2	0.50	0.41	1.17	0.0105	0.043	0.025	0.11	0.0150	0.0019	1.1
Inventive Steel 3	0.45	0.57	0.93	0.0151	0.012	0.032	0.19	0.0197	0.0033	0.3
Inventive Steel 4	0.41	0.66	0.89	0.0001	0.015	0.040	0.17	0.0165	-0.0042	1.7
Inventive Steel 5	0.35	0.89	0.84	0.0097	0.045	0.021	0.27	0.0088	-0.0020	6.9
Inventive Steel 6	0.30	0.90	1.08	0.0195	0.046	0.038	0.10	0.0140	-0.0057	7.3
Inventive Steel 7	0.48	0.59	0.75	0.0151	0.025	0.019	0.24	0.0095	-0.0001	1.6
Comparative Steel 1	**0.22**	0.62	1.06	0.0132	0.0363	0.035	0.11	0.0096	-0.0084	7.1
Comparative Steel 2	0.50	**1.12**	1.17	0.0105	0.0434	0.025	0.11	0.0150	0.0019	3.2
Comparative Steel 3	0.35	0.57	**1.43**	0.0151	0.0223	0.032	0.19	0.0197	0.0033	1.8
Comparative Steel 4	0.41	0.66	0.89	0.0001	0.0146	**0.009**	0.17	0.0105	0.0058	1.7
Comparative Steel 5	0.35	0.89	0.84	0.0097	0.0450	0.021	0.27	**0.0032**	-0.0076	6.9
Comparative Steel 6	0.34	0.64	1.11	0.0124	0.0326	0.018	0.30	0.0185	**0.0092**	4.3
Comparative Steel 7	0.49	0.48	0.86	0.0134	0.0100	0.047	0.26	0.0184	-0.0060	**-0.9**

[Table 2]

Category	Steel type	Heating temperat ure of steel piece (°C)	Average cooling rate to 400°C (°C/s)	*Area fracti on of ferrite (%)	Area fraction of AlN (%)	Tensile strength (MPa)	Room-temper ature impact toughn ess(J/c m^2)	Tool wear
Example 1	Inventive Steel 1	1090	0.5	32.1	0.032	773	83	good
Example 2	Inventive Steel 2	1090	0.5	27.4	0.038	871	63	good
Example 3	Inventive Steel 3	1090	0.5	28.9	0.047	875	66	good
Example 4	Inventive Steel 4	1090	0.5	30.3	0.055	836	87	good
Example 5	Inventive Steel 5	1090	0.5	33.1	0.031	726	86	good
Example 6	Inventive Steel 6	1090	0.5	32.3	0.047	717	85	good
Example 7	Inventive Steel 7	1090	0.5	28.0	0.032	848	65	good
Comparative Example 1	Comparative Steel 1	1090	0.5	31.1	0.032	637	97	good
Comparative Example 2	Comparative Steel 2	1090	0.5	25.2	0.038	938	**49**	good
Comparative Example 3	Comparative Steel 3	1090	0.5	33.1	0.047	839	**49**	good
Comparative Example 4	Comparative Steel 4	1090	0.5	30.3	**0.024**	836	**47**	good
Comparative Example 5	Comparative Steel 5	1090	0.5	33.1	**0.021**	721	**58**	good
Comparative Example 6	Comparative Steel 6	1090	0.5	33.7	0.032	764	**55**	good
Comparative Example 7	Comparative Steel 7	1090	0.5	27.7	0.041	922	**58**	**poor**
Comparative Example 8	Inventive Steel 1	1090	0.1	34.1	0.032	**684**	92	good
Comparative Example 9	Inventive Steel 2	1090	**10.0**	**19.7**	0.038	921	**53**	**poor**
Comparative Example 10	Inventive Steel 3	**1150**	0.5	28.9	**0.012**	875	**46**	good
* The area fraction of ferrite was measured in a region from the center to a quarter or more of the diameter of the steel rod wire from the surface.								

[0055] 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 an impact toughness of 60 J/cm^2 or more desired in the present disclosure, a tensile strength of 700 MPa or more, and good cutting tool wear properties.

[0056] On the contrary, the steel rod wires of Comparative Examples 1 to 10 not satisfying all of the conditions suggested by the present disclosure had one or more poor properties among tensile strength, impact toughness, and cutting tool wear depth.

[0057] Specifically, Comparative Steel 1 of Comparative Example 1 having a low C content could not satisfy the suggested tensile strength of 700 MPa or more, and Comparative Examples 2 and 3 having an excess of Si and an excess of Mn, respectively, had insufficient impact toughness. In addition, Comparative Examples 4 and 5 having Al and N contents lower than those suggested by the present disclosure could not satisfy the suggested AlN area fraction of 0.03% or more, and thus low impact toughness values were obtained. Although Comparative Examples 6 and 7 satisfied the chemical composition suggested by the present disclosure, the Relational Expressions 1 and 2 were not satisfied, thereby obtaining low impart toughness and poor cutting tool wear. Although Comparative Examples 8 to 10 also satisfied the chemical composition suggested by the present disclosure, the heating temperature of the steel piece was higher and the average cooling rate range to 400°C during cooling after rolling was not satisfied, so that impact toughness and tensile strength were out of the target values or cutting tool wear was poor.

[0058] 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]

[0059] According to the present disclosure, a non-quenched and tempered steel rod wire having improved impact toughness and machinability may be provided while solving environmental problems and reducing costs, 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, 0.015% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.007% to 0.02% of N, and the balance being Fe and inevitable impurities,

wherein a microstructure includes ferrite and pearlite, and
Relational Expression 1 below is satisfied:

$$\text{[Relational Expression 1] } [N]-[Al]/1.93 \leq 0.009.$$

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

$$\text{[Relational Expression 2] } -23[C]+[Si](5-2[Si])-4[Mn]+104[S]+3 \geq 0.$$

3. The non-quenched and tempered steel rod wire according to claim 1, wherein an area fraction of ferrite, measured in a region from the center to a quarter or more of the diameter of the steel rod wire from the surface, is 20% to 40%.

4. The non-quenched and tempered steel rod wire according to claim 1, wherein an area fraction of the formed AlN is 0.03% or more.

5. The non-quenched and tempered steel rod wire according to claim 1, wherein a size of the formed AlN is 150 nm or less.

6. The non-quenched and tempered steel rod wire according to claim 1, wherein the number of carbonitrides having an average equivalent circular diameter of 100 nm or less per unit area is 2 ea./μm^2 or more.

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

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

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

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

11. The non-quenched and tempered steel rod wire according to claim 1, wherein a product of the tensile strength and the room-temperature 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, 0.015% to 0.05% of sol.Al, 0.1% to 0.3% of Cr, 0.007% to 0.02% of N, and the balance being Fe and inevitable impurities at a temperature of 950°C to 1100°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 more than 0.1°C/s but not more than 5.0°C/s, and the steel rod wire satisfies the Relational Expression 1 below:

$$\text{[Relational Expression 1] } [N]-[Al]/1.93 \leq 0.009.$$

13. The method according to claim 12, wherein Relational Expression 2 below is satisfied:

$$\text{[Relational Expression 2] } -23[C]+[Si](5-2[Si])-4[Mn]+104[S]+3 \geq 0.$$

14. The method according to claim 12, wherein an area fraction of ferrite, measured in a region from the center to a quarter or more of the diameter of the steel rod wire from the surface.

15. The method according to claim 12, wherein an area fraction of AlN formed in the reheating process is 0.03% or more.

16. The method according to claim 12, wherein a size of AlN formed in the reheating process is 150 nm or less.

17. The method according to claim 12, wherein the number of carbonitrides having an average equivalent circular diameter of 100 nm or less per unit area is 2 ea./μm^2 or more.

18. The method according to claim 12, wherein a tensile strength is 700 MPa or more.

19. The method according to claim 12, wherein a yield strength is 350 MPa to 450 MPa.

20. The method according to claim 12, wherein a yield ratio is 0.45 to 0.65.

21. The method according to claim 12, wherein an impact toughness is 60 J/cm^2 or more.

22. The method according to claim 12, wherein a product of the tensile strength and the impact toughness is 30000 to 60000.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2023/007297

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; **C21D 8/02**(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 38/14(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), 질소(N), 인성(toughness), 페라이트(ferrite), 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	KR 10-2021-0077530 A (POSCO) 25 June 2021 (2021-06-25) See claims 1, 5 and 9-10 and tables 2-3.	1-22
A	JP 2004-225073 A (SUMITOMO METAL IND. LTD.) 12 August 2004 (2004-08-12) See claim 1.	1-22
A	JP 2017-186652 A (KOBE STEEL LTD. et al.) 12 October 2017 (2017-10-12) See claims 1-2.	1-22
A	KR 10-2020-0062439 A (POSCO) 04 June 2020 (2020-06-04) See claims 1 and 10.	1-22
A	JP 06-073490 A (AICHI STEEL WORKS LTD.) 15 March 1994 (1994-03-15) 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
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
05 September 2023	**05 September 2023**

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2023/007297

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JP 2017-186652 A	12 October 2017	JP 6758225 B2	23 September 2020
		TW 201805438 A	16 February 2018
		TW I642791 B	01 December 2018
		WO 2017-170756 A1	05 October 2017
KR 10-2020-0062439 A	04 June 2020	KR 10-2143075 B1	31 August 2020
JP 06-073490 A	15 March 1994	None	

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