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(54) HIGH-STRENGTH WIRE ROD HAVING SUPERIOR IMPACT TOUGHNESS AND MANUFACTURING METHOD THEREFOR

(57) The present invention relates to a high-strength wire rod superior in impact toughness and a manufacturing method therefor and, more particularly, to a high-strength wire rod having superior impact toughness, which can be preferably used as a material for industrial machines or automobiles exposed to various external load environments, and a manufacturing method therefor.

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Description

[Technical Field]

[0001] The present disclosure relates to a high-strength wire rod, superior in impact toughness, and a manufacturing method therefor, and more particularly, to a high-strength wire rod having superior impact toughness, which can preferably be used as a material for industrial machines or automobiles exposed to various external load environments, and a manufacturing method therefor.

[Background Art]

[0002] Recently, efforts to reduce emissions of carbon dioxide, a main cause of environmental pollution, have become a global issue. In line with this, there are active movements to regulate vehicle exhaust gas emissions. As a measure to comply with such regulations, automakers have been attempting to resolve the problem by improving fuel efficiency. However, to improve fuel efficiency, vehicles are required to be lightweight while having high performance, and thus, materials or components for vehicles have been required to have high strength. In addition, since the demand for stability against external impacts has also been increased, impact toughness is recognized as an important material property of a material or a component as well.

[0003] A wire rod having a ferrite or perlite structure is limited in terms of securing excellent strength and impact toughness. Generally, a material having the above-described structure may have high impact toughness, but strength thereof may be relatively low. High strength may be obtained when cold drawing is performed to increase strength, but there may be a disadvantage in which impact toughness may rapidly decrease in proportion to an increase in strength.

[0004] Thus, in general, to implement high strength along with excellent impact toughness, a bainite structure or a tempered martensite structure is used. A bainite structure may be obtained through a constant temperature transformation heat treatment using a hot-rolled steel material, and a tempered martensite structure may be obtained through a quenching and tempering heat treatment. However, as it is difficult to stably obtain such structures simply by using general hot rolling and continuous cooling processes, it is necessary to perform an additional heat treatment process described above using a hot-rolled steel material.

[0005] If high strength and excellent impact toughness are able to be secured without an additional heat treatment, a portion of a process from a material to manufacturing of a component may be omitted or may be simplified. Thus, there is an advantage in which productivity may improve and manufacturing costs may be lowered.

[0006] However, a wire rod with a stably obtained bainitic or martensitic structure has not been developed by simply using hot rolling and continuous cooling processes without an additional heat treatment process. Thus, demand for the development of such a wire rod has emerged.

[Disclosure]

[Technical Problem]

[0007] An aspect of the present disclosure is to provide a high-strength wire rod having superior impact toughness and a manufacturing method therefor without an additional heat treatment process.

[Technical Solution]

[0008] According to an aspect of the present disclosure, a high-strength wire rod is provided, the high-strength wire rod including, by wt%, less than 0.05% of C, excluding 0%, 0.05% or less of Si, excluding 0%, 3.0 to 4.0% of Mn, 0.020% or less of P, 0.020% or less of S, 1.0 to 3.0% of Ni, 0.0010 to 0.0030% of B, 0.010 to 0.030% of Ti, less than 0.0030% of N, 0.010 to 0.050% of Al, and the balance of Fe and inevitable impurities, and a microstructure includes 3 area% or less of a martensite-austenite (MA) constituent, including 0 area%, 2 area% or less of proeutectoid ferrite, including 0 area%, and 95 area% or higher of bainitic ferrite, including 100 area%.

[0009] According to another aspect of the present disclosure, a method of manufacturing a high-strength wire rod is provided, the method including reheating steel comprising, by wt%, less than 0.05% of C, excluding 0%, 0.05% or less of Si, excluding 0%, 3.0 to 4.0% of Mn, 0.020% or less of P, 0.020% or less of S, 1.0 to 3.0% of Ni, 0.0010 to 0.0030% of B, 0.010 to 0.030% of Ti, less than 0.0030% of N, 0.010 to 0.050% of Al, and a balance of Fe and inevitable impurities; obtaining a wire rod by hot-rolling the reheated steel; primarily cooling the wire rod at a speed of 10 to 20°C/sec to a temperature within a range of Bs°C to Bs+50°C; secondarily cooling the primarily cooled wire rod at a speed of 2 to 5°C/sec a temperature within a range of Bf-50 °C to Bf°C; and air-cooling the secondarily cooled wire rod.

[Advantageous Effects]

[0010] According to an example embodiment in the present disclosure, a wire rod of the present disclosure may have superior strength and impact toughness, and may accordingly be used as a material for industrial machines or automobiles exposed to various external load environments.

[0011] Also, a wire rod of the present disclosure may secure superior strength and impact toughness without an additional heat treatment process, and may thus be advantageous in an economical sense.

[0012] Various beneficial advantages and effects of the present disclosure are not limited to the above described features, and may easily be understood in the process of describing specific example embodiments of the present disclosure.

[Best Mode for Invention]

[0013] Hereinafter, a high-strength wire rod having excellent impact toughness, an aspect of the present disclosure, will be described in detail.

[0014] An alloy component and a desirable content range of a high-strength wire rod of the present disclosure will be described in detail. A content of each component described in the below description is based on weight% unless otherwise indicated.

C: less than 0.05% (excluding 0%)

[0015] Carbon (C) may be soluble to steel or may exist as carbide or cementite, and may improve strength of a wire rod. However, in the present disclosure, carbon is not intentionally added. Even if carbon is not included, there may be no difficulty in securing properties. However, considering a content of inevitably added carbon, 0% may be excluded.

[0016] The more the content of carbon increases, the more the ductility and impact toughness may decrease. Thus, it may be necessary to control a content of carbon to be within a certain range. Also, the more the content of carbon increases, the more the martensite-austenite (MA) constituent may be formed in the bainite transformation, which may deteriorate impact toughness. Considering the issue mentioned above, in the present disclosure, a content of carbon may be controlled to be less than 0.05%.

Si: 0.05% or less (excluding 0%)

[0017] Silicon (Si) is known as a deoxidation element along with aluminum, and is known as an element which may be soluble to ferrite and may be effective for increasing strength by strengthening solid solution of a steel material. In the present disclosure, silicon is not intentionally added. Even if silicon is not included, there may be no difficulty in securing property. However, considering a content of inevitably added carbon, 0% may be excluded.

[0018] By adding silicon, strength may greatly increase, but ductility and impact roughness may greatly decrease. Thus, in the case of a cooling forge component requiring sufficient ductility, addition of silicon is strictly limited. Also, silicon may interfere with precipitation of cementite in the bainite transformation such that carbon may be thickened on austenite, and accordingly, a martensite-austenite constituent may easily formed. In the present disclosure, a content of silicon may be controlled to be 0.05% or less to secure excellent impact toughness.

Mn: 3.0 to 4.0%

[0019] Manganese (Mn) may increase strength of a steel material, and may improve hardenability such that manganese may allow a low temperature structure, such as bainite or martensite, to be easily be formed at a relatively wide range of cooling speeds.

[0020] When a content of manganese is less than 3.0%, hardenability may not be sufficient such that it may be difficult to stably secure a low temperature structure through consecutive cooling processes after a hot-rolling process. When a content of manganese exceeds 4.0%, hardenability may excessively increase such that a martensite structure may be obtained even during air-cooling, and thus, the content may not be preferable.

P: 0.020% or less

[0021] Phosphorus (P) may be one of impurities inevitably added in steel. Phosphorus may be segregated into a grain boundary, and may degrade toughness of steel, and may decrease delayed fracture resistance. Thus, it may be preferable to not include phosphorus as possible. In the present disclosure, an upper limit content of phosphorus may be controlled to be 0.020%.

S: 0.020% or less

[0022] Sulfur (S) may be one of impurities inevitably added to steel. Similarly to phosphorus, sulfur may be segregated into a grain boundary and may degrade toughness, and may also form low melting point sulfide, which may adversely affect a hot-rolling process. Thus, it may be preferable to not include sulfur as possible. In the present disclosure, an upper limit content of sulfur may be controlled to be 0.020%.

Ni: 1.0 to 3.0%

[0023] Nickel (Ni) may work as an element which may improve hardenability along with manganese. Accordingly, nickel may decrease the formation of a martensite-austenite (M/A) constituent. When a content of nickel is less than 1.0%, hardenability may not be sufficient such that the effect of preventing the formation of a martensite-austenite constituent may be insignificant. When a content of nickel exceeds 3.0%, hardenability may excessively increase such that a martensite structure may be obtained, and thus, the content may not be preferable. A more preferable content of nickel may be 1.2 to 2.8%.

B: 0.0010 to 0.0030%

[0024] Boron (B) is an element which may improve hardenability. Boron may be dispersed to an austenite grain boundary and may prevent the formation of ferrite during cooling, and may allow bainite or martensite to be easily formed. However, when a content of boron is less than 0.0010%, the effect of addition of boron may not be expected, and when a content of boron exceeds 0.0030%, a further increase of the effect may not be expected, and grain boundary strength may degrade due to precipitation of boron-based nitride in a grain boundary, which may degrade hot-forming processability.

Ti: 0.010 to 0.030%

[0025] Titanium (Ti) may have great reactivity with nitrogen such that titanium may form nitride earlier than other elements. When TiN is formed by adding titanium, and most of nitrogen of steel is exhausted, titanium may prevent precipitation of BN and may allow boron to exist in a soluble state such that the effect of increase of hardenability may be obtained. However, when a content of titanium is less than 0.010%, the effect of addition of titanium may be insignificant, and when a content of titanium exceeds 0. 030%, coarse nitride may be formed, which may degrade mechanical properties.

N: less than 0.0030%

[0026] Preferably, nitrogen (N) may be maintained in a soluble state along with boron, and to greatly generate the effect of improving hardenability, nitrogen should not be added as possible. Nitrogen should also be limited to not allow a martensite-austenite constituent to be easily formed in bainite transformation. In the present disclosure, a content of nitrogen may be controlled to be less than 0.0030%.

Al: 0.010 to 0.050%

[0027] Aluminum is a strong deoxidation element, and may increase purity by removing oxygen of steel. Aluminum may also be combined with solute nitrogen of steel and may formAlN, which may improve impact toughness. Thus, in the present disclosure, aluminum mav be actively added. When a content of aluminum is less than 0.010%, it may be difficult to expect the effect of addition of aluminum, and when a content thereof exceeds 0.050%, a large amount of alumina inclusion may be created, which may greatly degrade mechanical properties.

[0028] A remainder other than the above-described composition is Fe. However, in a general manufacturing process, inevitable impurities from raw materials or a surrounding environment may be inevitably added, and thus, impurities may not be excluded. A person skilled in the art may be aware of the impurities, and thus, the descriptions of the impurities may not be particularly provided in the present disclosure.

[0029] When designing an alloy of steel having the composition range described above, it may be preferably to control contents of C, Si, and Ni to satisfy Relational Expression 1 as below.

[Relational Expression 1]

$$0.01 \leq ([C]+[Si])/[Ni] \leq 0.03$$

(where where C, Si, and Ni each indicate a content of a respective element by wt%)

[0030] In the present disclosure, carbon may deteriorate impact toughness by forming cementite or a martensite-austenite (M/A) constituent, and silicon may deteriorate impact toughness as silicon may be soluble to steel or may allow a martensite-austenite (M/A) constituent to be easily formed. Nickel may prevent the formation of a martensite-austenite (M/A) constituent by improving hardenability. Considering the characteristics described above, the inventors conducted researches and experiments and have founded that, when contents of carbon, silicon, and nickel satisfy Relational Expression 1, a wire rod having a bainitic ferrite structure with excellent strength and impact toughness may be provided.

[0031] Also, when designing an alloy of steel having the composition range described above, it may be preferably to control contents of Mn, Ti, N, and B to satisfy Relational Expression 2 as below. A more preferable range of Relational Expression 2 may be 10.0 or higher, and an even more preferable range may be 12.0 or higher.

[Relational Expression 2]

$$[Mn] + \{5([Ti]-3.5[N])/[B]\} \geq 5.0$$

(where Mn, Ti, N, and B each indicate a content of a respective element by wt%).

[0032] In the present disclosure, manganese may increase hardenability and may allow bainitic ferrite to be easily formed even when a cooling speed is relatively low. Also, titanium may be combined with nitrogen and may from nitride, and may allow boron to be sufficiently soluble to steel such that titanium may prevent the formation of ferrite and may allow bainitic ferrite to be easily formed. Considering the characteristics described above, the inventors conducted researches and experiments and have founded that, when contents of manganese, titanium, boron, and nitrogen satisfy Relational Expression 2, a wire rod having a bainitic ferrite structure with excellent strength and impact toughness may be provided.

[0033] In the description below, a microstructure of a high-strength wire rod having excellent impact toughness will be described in detail.

[0034] As a microstructure, the wire rod of the present disclosure may include 3 area% or less of a martensite-austenite (MA) constituent, including 0 area%, 2 area% or less of proeutectoid ferrite, including 0 area%, and 95 area% or higher of bainitic ferrite, including 100 area%. Thus, the wire rod of the present disclosure may have bainitic ferrite as a main structure, and may include a martensite-austenite (MA) constituent and proeutectoid ferrite as second phases, and area fractions of the elements may be limited to be less than 3% and 2%, respectively. Bainite may be denoted by various terms depending on a content of carbon or morphology. Generally, bainite may be denoted as upper/lower bainite in medium carbon (approximately 0.2 to 0.45wt%) or higher, and may be denoted as bainitic ferrite, acicular ferrite, granular ferrite, and the like, in a low carbon range, 0.2% or less. The wire rod of the present disclosure may have a bainitic ferrite structure among the structures.

[0035] As the wire rod of the present disclosure has a bainitic ferrite structure as a main structure, excellent strength and impact toughness may be secured at the same time. If general ferrite is a main structure, not bainitic ferrite, it may be advantageous in terms of impact toughness, but degradation of strength may not be prevented, and thus, it may not be preferable.

[0036] The higher the area fraction of a martensite-austenite constituent, it may be more advantageous in terms of strength of a wire rod, but impact toughness may be deteriorated. Considering the issue above, it may be preferable to control an area fraction of a martensite-austenite constituent to be low as possible. As described above, in the present disclosure, an area fraction of a martensite-austenite constituent may be controlled to be 3% or less.

[0037] Proeutectoid ferrite may be formed along a prior austenite grain boundary and may greately deteriorate impact toughness. Thus, it may also be preferable to control an area fraction of proeutectoid ferrite to be low. As described above, in the present disclosure, an area fraction of proeutectoid ferrite may be controlled to be 2% or less.

[0038] According to an example embodiment, a grain size of a martensite-austenite constituent is 5μm or less (excluding 0μm) . If a grain size exceeds 5μm an area of an interfacial surface in contact with a bainitic ferrite matrix may increase, which may deteriorate impact toughness . Herein, a grain size may refer to an equivalent circular diameter of each of particles detected by observing a cross-sectional surface of the wire rod.

[0039] The high-strength wire rod may be manufactured by various methods, and the manufacturing method is not particularly limited. However, as a preferable example embodiment, the high-strength wire rod may be manufactured by the method as described below.

[0040] In the description below, a method of manufacturing a high-strength wire rod having excellent impact toughness, another aspect of the present disclosure, will be described in detail.

[0041] A steel material having the above-described composition system may be prepared, and may be reheated. A form of the steel material may not be particularly limited, and generally, the steel material may have a bloom or billet form.

[0042] A preferable range of a reheating temperature may be 950 to 1050°C. The temperature range may be determined as above to prevent coarsening of a grain by performing the reheating of the steel material at a relatively low temperature.

[0043] A wire rod may be obtained by finish-hot-rolling the reheated steel material.

[0044] A preferable range of the finish-hot-rolling temperature may be 750 to 850°C. The temperature range may be determined as above to improve impact toughness by refining an austenite grain through a sufficient low temperature rolling process and consequently obtaining a fine bainite structure after phase transformation.

[0045] The wire rod may be primarily cooled at a speed of 10 to 20°C/sec to a temperature within a range of Bs°C to Bs+50°C. Bs may refer to a temperature from which bainite phase transformation starts on a consecutive cooling curve. In the present disclosure, the wire rod may be cooled at a relatively high speed to right before bainite phase transformation such that proeutectoid ferrite formed along an austenite grain boundary may be actively prevented.

[0046] In the present disclosure, a preferable temperature range of Bs may be 600 to 650°C.

[0047] The primarily cooled wire rod may be secondarily cooled at a speed of 2 to 5°C/sec to a temperature within a range of Bf-50 °C to Bf°C, and may be air-cooled. Bf may refer to a temperature at which bainite phase transformation terminates on a consecutive cooling curve. When the secondary cooling termination temperature exceeds Bf°C, it may be difficult to secure a sufficient amount of bainitic ferrite structure, and when the temperature is less than Bf-50°C, it may be easy to handle the steel material as the steel material is sufficiently cooled, but productivity may degrade.

[0048] Also, the secondary cooling speed is less than 2°C/sec, proeutectoid ferrite may be greatly formed, and when the speed exceeds 5°C/sec, martensite may be formed in the steel, which may deteriorate strength and impact toughness.

[0049] In the description below, an example embodiment of the present disclosure will be described in greater detail. It should be noted that the exemplary embodiments are provided to describe the present disclosure in greater detail, and to not limit the scope of rights of the present disclosure. The scope of rights of the present disclosure may be determined on the basis of the subject matters recited in the claims and the matters reasonably inferred from the subject matters.

[Mode for Invention]

(Embodiment)

[0050] Molten steel having an alloy composition indicated in Table 1 below was casted, and the molten steel was reheated at 1000°C, was wire-rod rolled to a diameter of 15mm (a finish hot-rolling temperature: 750°C), was primarily and secondarily cooled under conditions indicated in Table 2, and was air-cooled at 350°C or less, a Bf temperature, thereby manufacturing a wire rod. Bf, a bainite phase transformation terminating temperature, was measured using a dilatometer. Bf varied depending on a chemical composition, and had a range of approximately 350 to 400°C.

[0051] A microstructure of the wire rod manufactured as above was analyzed and the result is listed in Table 2, and tensile strength and impact toughness were measured and the result is listed in Table 2. An area fraction and a grain size of a martensite-austenite (MA) constituent of the microstructure of the wire rod were measured using an image analyzer.

[0052] A room temperature tensile test was conducted at a crosshead speed of 0. 9mm/min until a yield point and at 6mm/min thereafter. Also, in an impact test, a curvature of an edge of a striker which applied impact to samples was 2mm, and the impact test was carried out at a room temperature using an impact tester having a test capacity of 500J.

[Table 1]

Sample No.	Composition Elements (wt%)										Relational Expression 1	Relational Expression 2
	C	Si	Mn	Ni	Ti	B	N	P	S	Al		
1	0.04	0.01	3.2	2.6	0.017	0.0019	0.0029	0.015	0.007	0.027	0.019	21.2
2	0.01	0.05	3.4	2.0	0.023	0.0024	0.0025	0.009	0.009	0.033	0.030	33.1
3	0.03	0.03	3.5	2.2	0.027	0.0029	0.0020	0.011	0.006	0.021	0.027	38.0
4	0.02	0.02	3.7	1.4	0.013	0.0016	0.0023	0.012	0.008	0.042	0.029	19.2
5	0.03	0.03	3.9	2.0	0.015	0.0026	0.0027	0.008	0.007	0.036	0.030	14.6
6	0.03	0.03	3.6	0.1	0.021	0.0021	0.0024	0.014	0.005	0.025	0.600	33.6
7	0.15	0.05	3.2	2.3	0.026	0.0018	0.0028	0.010	0.010	0.032	0.087	48.2
8	0.04	0.3	3.5	1.8	0.023	0.0023	0.0021	0.016	0.006	0.038	0.189	37.5
9	0.02	0.02	2.3	2.0	0.017	0.0005	0.0023	0.015	0.004	0.022	0.020	91.8
10	0.03	0.04	3.4	1.6	0.016	0.0025	0.0025	0.009	0.008	0.030	0.044	17.9
11	0.04	0.02	3.3	2.4	0.022	0.0017	0.0022	0.013	0.007	0.034	0.025	45.4
12	0.03	0.03	3.5	2.2	0.005	0.0026	0.0029	0.012	0.012	0.029	0.027	-6.4
13	0.02	0.04	4.4	2.6	0.016	0.0019	0.0026	0.016	0.011	0.026	0.023	22.6
14	0.04	0.01	3.1	5	0.020	0.0017	0.0028	0.011	0.005	0.035	0.008	33.1

[Table 2]

Classification	Sample No.	Primary Cooling Speed (°C/s)	Primary Cooling Terminating Temperature (°C/s)	Secondary Cooling Speed (°C/s)	MA fraction (area%)	F fraction (area%)	Residual Structure	Tensile Strength (MPa)	Impact Toughness (J)
Inventive Steel	1	15	605	2	1	1.0	BF	642	213
	2	10	630	4	3	1.5	BF	660	204
	3	18	620	2.8	2	0.9	BF	646	212
	4	13	615	3.5	2	1.2	BF	633	217
	5	20	640	2.3	1	0.6	BF	638	220
Comparative Steel	6	11	610	2.2	5	1.5	BF	677	151
	7	17	645	3	8	0.9	BF	763	81
	8	16	635	4	9	1.0	BF	747	99
	9	14	620	2.7	2	8.0	BF	536	184
	10	18	640	8	10	1.0	BF+M	769	83
	11	12	630	0.1	1	5.0	BF	506	173
	12	15	625	3	2	7.0	BF	524	182
	13	13	635	5	3	1.2	BF+M	813	60
	14	19	615	4	2	0.8	BF+M	754	89

※ MA is a martensite-austenite constituent, F is proeutectoid ferrite, BF is bainitic ferrite, and M is martensite

[0053] As indicated in Table 1 and 2, samples 1 to 5 satisfying both of the alloy composition and process conditions suggested in the present disclosure had excellent tensile strength and impact toughness, which are, 600MPa or higher of tensile strength and 200J or higher of impact toughness.

[0054] As for sample 6, a content of nickel of sample 6 was below the range suggested in the present disclosure. Accordingly, a great amount of MA phase was formed, and impact toughness degraded.

[0055] As for sample 7, a content of carbon of sample 7 exceeded the range suggested in the present disclosure. Accordingly, tensile strength was excellent, but impact toughness was deteriorated. That is because carbon was solute on MA such that a stable MA phase was formed.

[0056] As for sample 8, a content of silicon of sample 8 exceeded the range suggested in the present disclosure. As a content of silicon was increased similarly to carbon, solution amount increased in a matrix such that the solution strengthening effect appeared, and MA phase also increased. Thus, even though tensile strength was excellent, impact toughness was degraded.

[0057] As for sample 9, contents of manganese and boron were below the range suggested in the present disclosure such that hardenability was low. Accordingly, even though the cooling condition suggested in the present disclosure was satisfied, ferrite and bainitic ferrite structure were duplex-established such that tensile strength was deteriorated.

[0058] As for sample 10, an alloy composition of sample 10 satisfied the range suggested in the present disclosure, but the composition relational expression (Relational Expression 1) and a speed of the secondary cooling in the manufacturing process exceeded the range suggested in the present disclosure. Accordingly, as a martensite-austenite constituent and martensite were formed, tensile strength was excellent, but impact toughness was deteriorated.

[0059] As for sample 11, an alloy composition of sample 11 satisfied the range suggested in the present disclosure, but a speed of the secondary cooling was below the range suggested in the present disclosure. Accordingly, as ferrite was formed, tensile strength was deteriorated.

[0060] As for sample 12, a content of titanium of sample 12 was below the range suggested in the present disclosure. As the amount of solute boron decreased, hardenability decreased, and when the cooling speed was also low, the mount of proeutectoid ferrite precipitation increased such that tensile strength was degraded.

[0061] As for samples 13 and 14, contents of manganese and nickel of samples 13 and 14 exceeded the ranges suggested in the present disclosure. In the samples, as hardenability was excessively increased, even when the steel was cooled at the cooling speed suggested in the present disclosure, martensite was created such that strength increased, but impact toughness was deteriorated.

[0062] While exemplary embodiments have been shown and described above, the scope of the present disclosure is not limited thereto, and it will be apparent to those skilled in the art that modifications and variations could be made without departing from the scope of the present invention as defined by the appended claims.

Claims

1. A high-strength wire rod, comprising:

   by wt%, less than 0.05% of C, excluding 0%, 0.05% or less of Si, excluding 0%, 3.0 to 4.0% of Mn, 0.020% or less of P, 0.020% or less of S, 1.0 to 3.0% of Ni, 0.0010 to 0.0030% of B, 0.010 to 0.030% of Ti, less than 0.0030% of N, 0.010 to 0.050% of Al, and a balance of Fe and inevitable impurities,
   wherein a microstructure comprises 3 area% or less of a martensite-austenite (MA) constituent, including 0 area%, 2 area% or less of proeutectoid ferrite, including 0 area%, and 95 area% or higher of bainitic ferrite, including 100 area%.

2. The high-strength wire rod of claim 1, wherein the high-strength wire rod satisfies Relational Expression 1 below,

   [Relational Expression 1]

   $$0.01 \leq ([C]+[Si])/[Ni] \leq 0.03$$

   where C, Si, and Ni each indicate a content of a respective element by wt%.

3. The high-strength wire rod of claim 1, wherein high-strength wire rod satisfies Relational Expression 2 below,

   [Relational Expression 2]

   $$[Mn] + \{5([Ti]-3.5[N])/[B]\} \geq 5.0$$

   where Mn, Ti, N, and B each indicate a content of a respective element by wt%.

4. The high-strength wire rod of claim 1, wherein a grain size of a martensite-austenite constituent is 5μm or less, excluding 0μm.

5. The high-strength wire rod of claim 1, wherein a content of Ni is 1.2 to 2.8 wt%.

6. A method of manufacturing a high-strength wire rod, comprising:

   reheating steel comprising less than 0.05% of C, excluding 0%, 0.05% or less of Si, excluding 0%, 3.0 to 4.0% of Mn, 0.020% or less of P, 0.020% or less of S, 1.0 to 3.0% of Ni, 0.0010 to 0.0030% of B, 0.010 to 0.030% of Ti, less than 0.0030% of N, 0.010 to 0.050% of Al, and a balance of Fe and inevitable impurities, by wt%;
   obtaining a wire rod by hot-rolling the reheated steel;
   primarily cooling the wire rod at a speed of 10 to 20°C/sec to a temperature within a range of Bs°C to Bs+50°C;

secondarily cooling the primarily cooled wire rod at a speed of 2 to 5°C/sec a temperature within a range of Bf-50 °C to Bf°C; and
air-cooling the secondarily cooled wire rod.

7. The method of claim 6, wherein a reheating temperature during the reheating the steel is 950 to 1050°C.

8. The method of claim 6, wherein a finish hot-rolling temperature during the hot-rolling is at is 750 to 850°C.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2017/013391

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/04(2006.01)i, C22C 38/02(2006.01)i, C22C 38/06(2006.01)i, C22C 38/08(2006.01)i, C22C 38/14(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 38/04; C21D 9/46; C22C 38/06; B21B 1/18; C22C 38/00; C21D 8/06; C22C 38/14; C22C 38/38; C22C 38/02; C22C 38/08; C21D 9/52

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: impact toughness, high strength, wire material, bainite, bainitic ferrite, martensite austenite constituent

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	KR 10-1536847 B1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 14 July 2015 See paragraphs [0142], [0167]-[0171], [0185], [0221]-[0228], [0245]-[0248] and claims 1, 3-4, 7.	1-5 6-8
A	KR 10-2004-0054987 A (POSCO) 26 June 2004 See abstract and claim 1.	1-8
A	CN 103060678 A (CENTRAL IRON & STEEL RESEARCH INSTITUTE) 24 April 2013 See abstract and claims 1-3.	1-8
A	JP 62-287012 A (KOBE STEEL LTD.) 12 December 1987 See claim 1.	1-8
A	KR 10-2016-0053776 A (POSCO) 13 May 2016 See paragraphs [0058]-[0061] and claims 1, 3-4, 7, 9-12.	1-8

☐ 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
"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 06 APRIL 2018 (06.04.2018)	Date of mailing of the international search report **06 APRIL 2018 (06.04.2018)**
Name and mailing address of the ISA/KR Korean Intellectual Property Office Government Complex-Daejeon, 189 Seonsa-ro, Daejeon 302-701, Republic of Korea Facsimile No. +82-42-481-8578	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2017/013391

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