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(54) HIGH STRENGTH STEEL WIRE HAVING EXCELLENT CORROSION RESISTANCE AND METHOD FOR MANUFACTURING SAME

(57) The present invention relates to a high strength steel wire and, more specifically, to a steel wire and a method for manufacturing the same, which can skip a heat treatment and have a high corrosion resistance as well as a high strength.

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Description

[Technical Field]

[0001] The present disclosure relates to a high strength steel wire, and more particularly, to a high strength steel wire having excellent corrosion resistance and a method for manufacturing the same.

[Background Art]

[0002] An armor cable is a reinforcing material supporting the load on a flexible pipe transporting crude oil at sea, and requires high strength, as well as corrosion resistance in a corrosive environment.

[0003] A method for obtaining required physical properties in the armor cable may be as follows.

[0004] First is a method of increasing the strength of material itself by adding a large amount of elements that increase the strength of steel. A representative example of strength increasing elements of steel is carbon. As the carbon content increases, the fraction of cementite, a hard phase, increases in a wire rod, and the lamellar spacing of a pearlite structure becomes significantly small, thereby improving the strength of a material.

[0005] However, carbon is effective for improving strength, but inhibits corrosion resistance. Therefore, there is a limit to selecting an appropriate content according to a use environment.

[0006] Second is a method of drastically improving strength by drawing out a wire rod and imparting work hardening thereto. The drawing material is obtained by drawing and heat treating a rolled wire rod to be processed to form a final wire. When such a wire drawing process is carried out, the lamellar spacing becomes significantly small, the work hardening coefficient increases, and dislocations accumulate, thereby imparting work hardening.

[0007] Third, strength of a tire cord material may be improved by increasing drawing strain on the tire cord material. In this case, since the drawing strain of the material is closely related to ductility of the material, if there is no disconnection in a workpiece itself during a drawing process and the process thereof is facilitated, the material may be advantageous to improve strength.

[0008] However, since in an alloying composition, manufacturing conditions, a structure, and the like are related mutually to change the strength of a steel material, the above-described methods have limitations in improving strength by independently controlling an alloying composition, manufacturing conditions, a structure, and the like. In addition, the above methods are not considered in terms of corrosion resistance of a high strength steel wire, and thus, there is a limit to improving corrosion resistance.

[Disclosure]

[Technical Problem]

[0009] An aspect of the present disclosure is to provide a steel wire having high strength as well as high corrosion resistance even with the omission of a heat treatment, and a method for manufacturing the same.

[Technical Solution]

[0010] According to an aspect of the present disclosure, a high strength steel wire having excellent corrosion resistance includes, by weight%, 0.07 to 0.15% of carbon (C), 2.7 to 3.5% of manganese (Mn), 0.10 to 0.50% of silicon (Si), 0.8% or less (including 0%) of chromium (Cr), 0.01 to 0.02% of titanium (Ti), 0.001 to 0.003% of boron (B), and a remainder of iron (Fe) and other unavoidable impurities. As a microstructure of the high strength steel wire, a bainite phase is included therein.

[0011] According to another aspect of the present disclosure, a method of manufacturing a high strength steel wire having excellent corrosion resistance includes producing a wire rod satisfying the alloy composition described above; cold-drawing the wire rod at a total reduction ratio of 40 to 80% to produce a cold drawn wire rod; and cold-rolling the cold drawn wire rod at a total reduction ratio of 50 to 90% to produce a cold rolled material.

[Advantageous Effects]

[0012] According to an embodiment of the present disclosure, a steel wire having high strength, even with the omission of an LP heat treatment process, may be provided, and a steel wire according to an embodiment of the present disclosure exhibits an effect of securing excellent corrosion resistance.

[0013] Accordingly, a steel wire according to an embodiment of the present disclosure may be advantageously applicable to usage of requiring high strength and high corrosion resistance.

[Best Mode]

[0014] The inventors have conducted in-depth research to provide a steel wire that may be suitably used in environments requiring high corrosion resistance as well as high strength. As a result, it has been found that a steel wire having a microstructure advantageous for simultaneously securing both high strength and high corrosion resistance may be provided by optimizing an alloy composition and manufacturing conditions of steel, and thus the present disclosure has been obtained.

[0015] Hereinafter, an embodiment of the present disclosure will be described in detail.

[0016] A high strength steel wire having excellent corrosion resistance according to an embodiment of the present disclosure may include, by weight%, 0.07 to 0.15% of carbon (C), 2.7 to 3.5% of manganese (Mn), 0.10 to 0.50% of silicon (Si), 0.8% or less (including 0%) of chromium (Cr), 0.01 to 0.02% of titanium (Ti), and 0.001 to 0.003% of boron (B).

[0017] Hereinafter, the reason that the alloy composition of a steel wire provided in the present disclosure is controlled as described above will be described in detail. In this case, the content of respective elements refers to weight% unless otherwise specified.

C: 0.07 to 0.15%

[0018] Carbon (C) is an element favorable for improving the strength of a steel wire. If the content of C is less than 0.07%, the strength is lowered. On the other hand, if the content of C exceeds 0.15%, the strength is improved, while ductility is decreased. In detail, corrosion resistance characteristics of the steel wire tend to decrease as the content of C increases.

[0019] In the present disclosure, the content of C may be controlled to be 0.07 to 0.15% in terms of ensuring strength and corrosion resistance of the steel wire. In more detail, the content of C may be 0.09 to 0.13%.

Mn: 2.7 to 3.5%

[0020] Manganese (Mn) is an element to secure an intended microstructure as well as improving quenching properties of a steel wire. If the content of Mn is less than 2.7%, it may be difficult to secure quenching properties, and thus, there is a problem in which a required microstructure and strength may not be obtained. On the other hand, if the content of Mn exceeds 3.5%, there is a problem in which ductility is significantly lowered.

[0021] Therefore, in the present disclosure, the content of Mn may be controlled to be 2.7 to 3.5%, and, in more detail, 2.8 to 3.3%.

Si: 0.10 to 0.50%

[0022] Silicon (Si) is an element favorable for a deoxidation effect, and Si may be added in an amount of 0.10% or more to obtain a sufficient deoxidation effect. If the content of Si is less than 0.10%, a deoxidation effect is insufficient and there is a possibility that inclusions will increase, which leads to a high possibility that ductility and corrosion resistance will be degraded. On the other hand, if the content of Si exceeds 0.50%, drawability and plate rolling properties are deteriorated.

[0023] Therefore, in the present disclosure, the content of Si may be controlled to be 0.10 to 0.50%, and, in more detail, 0.15 to 0.40%.

Cr: 0.8% or Less

[0024] Chromium (Cr) is an element favorable for securing a bainite phase as the microstructure of a steel wire by securing quenching properties, and is also an element for strength improvement.

[0025] In the present disclosure, Cr may be further included for the above-mentioned effect, but if the content exceeds 0.8%, there is a fear that a martensite phase may be formed as a microstructure, to deteriorate drawability.

[0026] Therefore, in the present disclosure, the content of Cr may be controlled to be 0.8% or less when Cr is added, and even in a case in which Cr is not added, since a required microstructure and strength may be secured, 0% is included.

Ti: 0.01 to 0.02%

[0027] Titanium (Ti) is a most reactive element with nitrogen (N), and forms nitrides in the steel. In the present disclosure, by adding Ti to form TiN, most nitrogen in the steel is exhausted, such that the formation of BN may be significantly reduced by reacting boron (B) with the N. For example, by allowing the B to exist in a soluble state, the improvement in hardenability may be obtained.

[0028] For the above-mentioned effect, Ti may be added in an amount of 0.01% or more, but when the content exceeds 0.02%, a coarse nitride is formed to deteriorate mechanical properties.
[0029] Therefore, in the present disclosure, the Ti content may be controlled to be 0.01 to 0.02%, and in more detail, to be 0.012 to 0.07%.

B: 0.001 to 0.003%

[0030] Boron (B) is an element which is advantageous for improving hardenability of steel, and provides an effect of diffusing into an austenite grain boundary system to suppress formation of ferrite during cooling and increase quenching properties.
[0031] To sufficiently obtain the above-mentioned effect, B may be added in an amount of 0.001% or more. However, if the content exceeds 0.003%, not only the above effect is saturated but also boron-based nitride precipitates, deteriorating grain boundary strength and lowering hot workability.
[0032] Therefore, in the present disclosure, the content of B may be controlled to be 0.001 to 0.003%.
[0033] In an embodiment of the present disclosure, the remainder is iron (Fe). However, in an ordinary manufacturing process, impurities which are not intended may be inevitably incorporated from a raw material or a surrounding environment, which cannot be excluded. These impurities are known to those skilled in the manufacturing field, and thus, are not specifically mentioned in this specification.
[0034] On the other hand, as described above, an upper limit of the nitrogen (N) forming the TiN may be limited to 0.005%, such that boron (B) in steel may be maintained in a solid solution state, instead of precipitates (ex., BN), to sufficiently exhibit an effect of improving hardenability.
[0035] Further, since sulfur (S) forms low melting sulfides to deteriorate hot rolling properties and deteriorate drawing processability, an upper limit of S may be limited to 0.015%.
[0036] A steel wire according to an embodiment of the present disclosure satisfying the alloy composition described above may include a bainite single phase as a microstructure.
[0037] To secure high strength of a steel wire in an embodiment of the present disclosure, instead of forming a pearlite phase having fine lamellar spacing, a uniform bainite phase with a microstructure may be formed, thereby providing a steel wire having high strength and high corrosion resistance, and simultaneously, providing a technical significance in that an existing LP heat treatment process may be omitted.
[0038] In addition to the alloy composition described above, the steel wire according to an embodiment of the present disclosure, having a bainite phase as a microstructure, has a yield strength of 1100 MPa or more and a tensile strength of 1200 MPa or more. Thus, the steel wire according to an embodiment has not only high strength but also excellent corrosion resistance in which sulfuric acid corrosion loss is 800g/mm$^{2}\cdot$h or lower.
[0039] Hereinafter, a method of manufacturing a high strength steel wire having excellent corrosion resistance, according to another embodiment in the present disclosure, will be described in detail.
[0040] A steel wire according to an embodiment in the present disclosure may be produced by a process of manufacturing a wire rod satisfying the above-described alloy composition, and then, of drawing the wire rod.
[0041] Although the wire rod may be manufactured through a variety of wire rod manufacturing techniques known in the art, in detail, the wire rod may be manufactured through a series of processes to be described below.
[0042] First, a billet satisfying the above-mentioned alloy composition is manufactured, and may then be subjected to a heating process of homogenizing the billet.
[0043] A microstructure of the billet may be formed as an austenite single phase through the heating process.
[0044] To this end, the heating may be performed in a temperature range of 1000 to 1100°C. If the heating temperature is less than 1000°C, it may be difficult to secure a temperature region in subsequent wire rolling. If the heating temperature exceeds 1100°C, austenite grains are formed coarsely and a target level of strength may be difficult to secure.
[0045] The billet heated as described above may be subjected to wire rolling, and then, may be cooled to be produced as a wire rod.
[0046] In this case, as the wire rolling, finishing hot rolling may be performed in a temperature range of 950 to 1100°C. If a temperature during the finishing hot rolling is less than 950°C, there is a problem in which roll life is reduced due to an increase in a rolling load. On the other hand, if the temperature exceeds 1100°C, the grain size becomes coarse, and thus, ductility may be reduced. Further, in this case, decarburization may occur excessively, thereby deteriorating drawability.
[0047] Thereafter, a wire rod having a bainite phase may be manufactured by cooling at a cooling rate of 1 to 3°C/s. If the cooling rate is less than 1°C/s, there is a fear that a structure such as pearlite or the like, other than the bainite phase, may be formed as a microstructure, while if the cooling rate exceeds 3°C/s, there is a fear that a martensite phase may be formed.
[0048] A steel wire may be manufactured by drawing the wire rod manufactured as described above. In the present disclosure, descriptions of an LP heat treatment generally performed before the wire rod is drawn will be omitted.

[0049] According to an embodiment in the present disclosure, since the wire rod having a uniform bainite phase, without a ferrite structure, is subjected to a drawing process, homogeneity and a relatively high work-hardening ratio may be secured without performing a separate LP heat treatment.

[0050] In more detail, the wire rod may be directly cold-drawn without a LP heat treatment process, and in this case, a cold drawn wire rod may be manufactured by performing cold drawing on the wire rod at a reduction ratio of 40 to 80% in total.

[0051] If the reduction ratio is less than 40% in cold drawing, since the amount of drawing processing is insufficient, sufficient strength may not be secured. On the other hand, if the reduction ratio exceeds 80%, cracks may occur.

[0052] The cold drawn wire rod as described above may have a yield strength of 1000 MPa or more and a tensile strength of 1100 MPa or more.

[0053] Subsequently, the cold drawn wird rod may be cold rolled, and in this case, a cold rolled material may be produced by cold rolling at a total reduction ratio of 50 to 90%.

[0054] The cold rolling is to obtain a steel wire having a plate-like shape. If the reduction ratio in this case is less than 50%, a processing amount is insufficient and sufficient strength may not be ensured. On the other hand, if the reduction ratio exceeds 90%, cracks may occur.

[0055] The cold-rolled material as described above may have a yield strength of 1100 MPa or more and a tensile strength of 1200 MPa or more.

[0056] Hereinafter, embodiments in the present disclosure will be described in further detail by way of example. It should be noted, however, that the following embodiments are intended to illustrate the present disclosure in more detail and not to limit the scope of the present disclosure. The scope of the present disclosure is determined by the matters set forth in the claims and the matters reasonably inferred therefrom.

[Mode for Invention]

(Embodiment)

[0057] A billet having an alloy composition shown in the following Table 1 was prepared, and then, the billet was heated at 1000 to 1100°C and then hot-rolled at 1000°C to produce a wire rod. Thereafter, the wire rod was cooled to 500°C at a cooling rate of 1 to 3°C/s, followed by air-cooling to room temperature.

[0058] Then, Inventive Steels 1 to 6, which satisfy an alloy composition proposed in the present disclosure, were cold rolled at a total reduction ratio of 50 to 90%, after performing drawing at a total reduction ratio of 40 to 80%, thereby producing a steel wire. Comparative Steels 1 to 4 were subjected to an LP heat treatment and then subjected to a drawing process (a total reduction ratio of 40 to 80%) and cold rolling (a total reduction ratio of 50 to 90%).

[0059] Tensile properties of respective wire rods and steel wires fabricated above were evaluated by a room temperature tensile test. Corrosion loss of the respective steel wires was measured by immersing a steel wire in 5% sulfuric acid solution. The results are shown in Table 2 below.

[Table 1]

Classification	Alloy Composition (Weight%)							
	C	Si	Mn	Cr	S	Ti	B	N
Inventive Steel 1	0.11	0.15	3.0	-	0.004	0.015	0.002	0.004
Inventive Steel 2	0.11	0.15	3.0	0.5	0.004	0.015	0.002	0.004
Inventive Steel 3	0.12	0.16	3.1	-	0.004	0.016	0.002	0.004
Inventive Steel 4	0.13	0.13	3.3	-	0.003	0.012	0.002	0.004
Inventive Steel 5	0.10	0.16	2.8	0.6	0.004	0.013	0.002	0.003
Inventive Steel 6	0.10	0.14	2.7	0.4	0.003	0.017	0.002	0.005
Comparative Steel 1	0.35	0.20	0.7	-	0.004	-	-	0.006
Comparative Steel 2	0.32	0.24	0.8	-	0.005	-	-	0.007
Comparative Steel 3	0.38	0.17	0.6	-	0.005	-	-	0.006
Comparative Steel 4	0.33	0.18	1.3	-	0.011	0.03	0.07	0.008

[Table 2]

Classification	LP Heat Treatment	Wire Rod		LP Material		Cold Rolling Wire (Steel Wire)		Corrosion Loss ($g/mm^2 \cdot h$)
		YS	TS	YS	TS	YS	TS	
Inventive Steel 1	Not Performed	480	757	-	-	1230	1331	527
Inventive Steel 2	Not Performed	584	895	-	-	1344	1474	539
Inventive Steel 3	Not Performed	483	762	-	-	1241	1332	532
Inventive Steel 4	Not Performed	479	761	-	-	1232	1342	518
Inventive Steel 5	Not Performed	596	901	-	-	1349	1489	548
Inventive Steel 6	Not Performed	573	881	-	-	1330	1463	532
Comparative Steel 1	Performed	293	327	451	687	1090	1187	1093
Comparative Steel 2	Performed	287	319	448	673	1073	1163	1087
Comparative Steel 3	Performed	312	334	467	692	1118	1203	1218
Comparative Steel 4	Performed	332	347	505	714	1147	1198	1196

(In Table 2, YS refers to yield strength, TS refers to tensile strength, and the unit is MPa.)

[0060] As shown in Tables 1 and 2, it can be confirmed that in the case of Inventive Steels 1 to 6 satisfying alloy compositions according to an embodiment of the present disclosure, strength of wire rods (yield strength and tensile strength) is improved in comparison with Comparative Steels 1 to 4. In addition, it can be confirmed that the strength of steel wires of Inventive Steels 1 to 6 is also higher than that of Comparative Steels 1 to 4 subjected to an LP heat treatment.

[0061] In other words, in the case of Inventive Steels 1 to 6 having a bainite phase as a microstructure, a work hardening rate is relatively high, and thus, required high strength may be obtained through a drawing process and cold rolling without performing an LP heat treatment, as compared with Comparative Steels 1 to 4 having a pearlite phase.

[0062] In addition, Inventive Steels 1 to 6 exhibited a corrosion loss of $550g/mm^2 \cdot h$ or lower, which indicates that a corrosion rate was reduced by about 50% under the same conditions as Comparative Steels 1 to 4.

[0063] As a result, the corrosion resistance may be improved by removing a ferrite phase which adversely affects corrosion resistance characteristics of a steel wire and forming a bainite phase.

Claims

1. A high strength steel wire having excellent corrosion resistance, comprising:

   by weight%, 0.07 to 0.15% of carbon (C), 2.7 to 3.5% of manganese (Mn), 0.10 to 0.50% of silicon (Si), 0.8% or less (including 0%) of chromium (Cr), 0.01 to 0.02% of titanium (Ti), 0.001 to 0.003% of boron (B), and a remainder of iron (Fe) and unavoidable impurities,
   wherein as a microstructure of the steel wire, a bainite phase is included in the steel wire.

2. The high strength steel wire having excellent corrosion resistance of claim 1, wherein the steel wire has a sulfuric acid corrosion loss of $800g/mm^2 \cdot h$ or less.

3. The high strength steel wire having excellent corrosion resistance of claim 1, wherein the steel wire has a yield strength of 1100 MPa or more and a tensile strength of 1200 MPa or more.

4. A method of manufacturing a high strength steel wire having excellent corrosion resistance, the method comprising:

producing a wire rod including, by weight%, 0.07 to 0.15% of carbon (C), 2.7 to 3.5% of manganese (Mn), 0.10 to 0.50% of silicon (Si), 0.8% or less (including 0%) of chromium (Cr), 0.01 to 0.02% of titanium (Ti), 0.001 to 0.003% of boron (B), and a remainder of iron (Fe) and unavoidable impurities;
cold-drawing the wire rod at a total reduction ratio of 40 to 80% to produce a cold drawn wire rod; and
cold-rolling the cold drawn wire rid at a total reduction ratio of 50 to 90% to produce a cold rolled material.

5. The method of manufacturing a high strength steel wire having excellent corrosion resistance of claim 4, wherein the producing of the wire rod comprises preparing a billet; heating the billet at a temperature of 1000 to 1100°C; finishing wire-rolling the heated billet at a temperature of 950 to 1100°C to produce a wire rod; and cooling the wire rod at a cooling rate of 1 to 3°C/s.

6. The method of manufacturing a high strength steel wire having excellent corrosion resistance of claim 4, wherein the cold drawn wire rod has a yield strength of 1000 MPa or more and a tensile strength of 1100 MPa or more.

7. The method of manufacturing a high strength steel wire having excellent corrosion resistance of claim 4, wherein the cold rolled material has a yield strength of 1100 MPa or more and a tensile strength of 1200 MPa or more.

INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/38(2006.01)i, C22C 38/02(2006.01)i, C22C 38/04(2006.01)i, C22C 38/28(2006.01)i, C22C 38/32(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 38/38; C21D 8/06; B21B 1/16; C22C 38/04; B21C 1/00; C22C 38/02; C22C 38/28; C22C 38/32; 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: bainite phase, corrosion resistance, high strength steel wire, wire material, cold drawing, cold rolling

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 10-2016-0063553 A (POSCO) 07 June 2016 See paragraphs [0039]-[0052]; and claims 1-6.	1
Y		2-7
Y	JP 08-164413 A (SUMITOMO METAL IND., LTD.) 25 June 1996 See paragraphs [0012]-[0048]; and claims 1-3.	2-7
A	KR 10-2016-0063563 A (POSCO) 07 June 2016 See paragraphs [0030]-[0063]; and claims 1-6.	1-7
A	KR 10-2016-0063534 A (POSCO) 07 June 2016 See paragraphs [0024]-[0044]; and claims 1-5.	1-7
A	KR 10-2016-0075957 A (POSCO) 30 June 2016 See paragraphs [0009]-[0032]; and claims 1-6.	1-7

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

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"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
06 MARCH 2018 (06.03.2018)	**06 MARCH 2018 (06.03.2018)**

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Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2017/013821

Patent document cited in search report	Publication date	Patent family member	Publication date
KR 10-2016-0063553 A	07/06/2016	KR 10-1676112 B1	30/11/2016
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KR 10-2016-0075957 A	30/06/2016	NONE	

Form PCT/ISA/210 (patent family annex) (January 2015)