(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 265 768 A1

(12) EUROPEAN PATENT APPLICATION
published in accordance with Art. 153(4) EPC

(43) Date of publication:
25.10.2023 Bulletin 2023/43

(21) Application number: **21906896.2**

(22) Date of filing: **18.11.2021**

(51) International Patent Classification (IPC):
C22C 38/02 $^{(2006.01)}$ ***C22C 38/04*** $^{(2006.01)}$
C21D 9/52 $^{(2006.01)}$ ***C21D 8/06*** $^{(2006.01)}$

(52) Cooperative Patent Classification (CPC):
C21D 8/06; C21D 9/52; C22C 38/02; C22C 38/04

(86) International application number:
PCT/KR2021/016988

(87) International publication number:
WO 2022/131591 (23.06.2022 Gazette 2022/25)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **15.12.2020 KR 20200175304**

(71) Applicant: **POSCO Co., Ltd**
Pohang-si, Gyeongsangbuk-do 37859 (KR)

(72) Inventor: **LEE, Choongyeol**
Pohang-si Gyeongsangbuk-do 37669 (KR)

(74) Representative: **Nederlandsch Octrooibureau**
P.O. Box 29720
2502 LS The Hague (NL)

(54) STEEL WIRE WITH IMPROVED DRAWABILITY, AND MANUFACTURING METHOD THEREFOR

(57) A steel wire with improved drawability, and a manufacturing method therefor are disclosed. A steel wire according to the present invention comprises, by wt%, 0.52-0.69% of C, 0.3-0.8% of Mn, 0.1-0.5% of Si, and the balance of Fe and inevitable impurities, wherein the carbon content of cementite in pearlite is 7 at.% or more, and the following formula (1) is satsified.

$$(1)\ [TS]+\exp(\varepsilon)*10 < 1500 \tag{1}$$

In Expression (1), [TS] means the tensile strength (MPa) of a wire before drawing, and ε means draw strain.

EP 4 265 768 A1

Description

[Technical field]

[0001] The present invention relates to a steel wire with improved drawability and a method for manufacturing the same, and more specifically, to a steel wire without delamination and with improved torsion properties and drawability, and a method for manufacturing the same.

[Background Art]

[0002] In general, various methods can be used to obtain a high-strength steel wire.
[0003] First, a method of increasing the strength of the material itself may be used. That is, as one of the methods for obtaining a high-strength steel wire, a method of increasing the strength of the material itself by adding a large amount of a reinforcing element that increases the strength of the steel may be used. A typical example of such a reinforcing element is carbon. When a carbon content is increased, a fraction of cementite, which is a hard phase, inside a wire rod increases and the lamellar spacing of a pearlite structure becomes denser, so that the strength of the material is improved. Techniques for adding various alloying elements in addition to carbon have been proposed.
[0004] Alternatively, strength can be improved by increasing the drawing strain of the steel wire. At this time, the drawing strain of the material is closely related to the ductility of the material, and it is advantageous to improve the strength as the material itself is easily processed without disconnection during drawing.
[0005] When a large amount of alloying elements are simply added to improve the strength of the wire rod, problems such as disconnection may occur due to poor ductility of the wire rod in a subsequent manufacturing process of the steel wire after rolling the wire rod. Therefore, the most economical method among methods for increasing the strength of the steel wire is a method of reducing the amount of alloying elements and increasing the drawing strain.
[0006] However, delamination usually occurs when the drawing strain increases, and when delamination occurs during a torsion test of a steel wire, it is regarded as a defect, and the maximum drawing strain at which delamination does not occur is defined as a drawing limit.
[0007] The occurrence of delamination is related to cementite decomposition, and when cementite decomposition occurs due to an increase in drawing strain, carbon from cementite is released into ferrite, thereby rapidly reducing the plastic deformability of ferrite and generating cracks. This acts as a major obstacle to the high strength of the steel wire.
[0008] Therefore, a high-strength steel wire capable of suppressing the occurrence of delamination while increasing the drawing strain is required.

[Disclosure]

[Technical Problem]

[0009] The present invention is directed to providing a steel wire with improved drawability by controlling the strength of a wire rod and slowing down a decomposition rate of cementite, and a method for manufacturing the same.

[Technical Solution]

[0010] A steel wire having improved drawability according to one embodiment of the present invention includes, in weight percent, C: 0.52 to 0.69%, Mn: 0.3 to 0.8%, Si: 0.1 to 0.5%, a balance of Fe, and unavoidable impurities, has a carbon content of cementite in pearlite of 7 at% or more, and satisfies the following Expression (1).

$$(1)\ TS+\exp(\varepsilon)*10 < 1500$$

[0011] In Expression (1), TS denotes a tensile strength (MPa) of a wire rod before drawing, and ε denotes a drawing strain.
[0012] A tensile strength of a wire rod may be 700 to 1,000 MPa.
[0013] The torsion number of the steel wire may be 30 or more.
[0014] Delamination may not occur in the steel wire at a drawing strain of 4.02 or less.
[0015] A method for manufacturing a steel wire for a spring with improved fatigue life and toughness according to one embodiment of the present invention includes: hot-rolling a billet including, in weight percent, C: 0.52 to 0.69%, Mn: 0.3 to 0.8%, Si: 0.1 to 0.5%, a balance of Fe, and unavoidable impurities to obtain a wire rod; cooling the hot-rolled wire rod at a cooling rate of 3 to 20 °C/s; and obtaining a steel wire by drawing the cooled wire rod to satisfy the following

Expression (1).

$$(1)\ [TS]+\exp(\varepsilon)*10 < 1500$$

[0016] In Expression (1), [TS] denotes a tensile strength (MPa) of a wire rod before drawing, and ε denotes a drawing strain.

[0017] During drawing, delamination may not occur at a drawing strain of 4.02 or less.

[Advantageous Effects]

[0018] In a steel wire according to an embodiment of the present invention, the occurrence of delamination can be suppressed and torsion properties and a drawing limit can be increased even during drawing with a high drawing strain by controlling the strength of a wire rod and slowing down a decomposition rate of cementite.

[0019] Specifically, the steel wire according to the embodiment of the present invention can secure a torsion number of 27 or more even at a drawing strain of 4.02, and since delamination does not occur during drawing, a drawing limit can be increased and, ultimately, a steel wire having ultra-high strength can be provided.

[Modes of the Invention]

[0020] A steel wire having improved drawability according to an embodiment of the present invention includes, in weight percent, C: 0.52 to 0.69%, Mn: 0.3 to 0.8%, Si: 0.1 to 0.5%, a balance of Fe, and unavoidable impurities, has a carbon content of cementite in pearlite of 7 at% or more, and satisfies the following Expression (1).

$$(1)\ TS+\exp(\varepsilon)*10 < 1500$$

[0021] In the above Expression (1), TS denotes a tensile strength (MPa) of a wire rod before drawing, and ε denotes a drawing strain.

[0022] This specification does not describe all elements of the embodiments, and general content or overlapping content between the embodiments in the technical field to which the present invention pertains will be omitted.

[0023] In addition, when a portion is said to "comprise" a component, this means that the component may further comprise other components, rather than excluding other components, unless specifically stated to the contrary.

[0024] Singular expressions include plural expressions unless the context clearly dictates otherwise.

[0025] Hereinafter, the present invention will be described in more detail.

[0026] A steel wire having improved drawability according to an embodiment of the present invention includes, in weight percent, C: 0.52 to 0.69%, Mn: 0.3 to 0.8%, Si: 0.1 to 0.5%, a balance of Fe and unavoidable impurities, has a carbon content of cementite in pearlite of 7 at% or more after drawing, and satisfies the following Expression (1).

$$(1)\ [TS]+\exp(\varepsilon)*10 < 1500$$

[0027] In Expression (1), [TS] denotes a tensile strength (MPa) of the wire rod before drawing, and ε denotes the drawing strain.

[0028] Hereinafter, the reason for limiting a numerical value of an alloy component element content in an embodiment of the present invention will be described. Hereinafter, unless otherwise specified, units are % by weight.

[0029] A content of C is 0.52 to 0.69%.

[0030] C is an element added to improve the strength of the steel wire. When a C content is less than 0.52%, a strength improvement effect is not sufficient, and when the C content exceeds 0.69%, the strength of the steel can be secured but ductility is reduced, so that in the present invention, it is preferable to control the C content to 0.52 to 0.69%.

[0031] A content of Mn is 0.3 to 0.8%.

[0032] Mn is an effective element for increasing hardenability. When an Mn content is less than 0.3%, the above-mentioned effect cannot be sufficiently obtained, and when the Mn content exceeds 0.8%, centerline segregation may occur, and the possibility of causing a low-temperature structure is very high, so that it is preferable to control the Mn content to 0.3 to 0.8% in the present invention.

[0033] A content of Si is 0.1 to 0.5%.

[0034] Si is an effective element for increasing the cleanliness of a wire rod and strengthening steel by being employed in ferrite, which is a base structure, to improve strength. When a Si content is less than 0.1%, the above-mentioned effect cannot be obtained, and when the Si content is more than 0.5%, if the amount of drawing is large, it may be a crack propagation path, and ductility is rapidly reduced to deteriorate drawability, so that the Si content is preferably controlled to 0.1 to 0.5%.

[0035] In addition to the above composition, the remainder is Fe, and includes other impurities inevitably mixed in manufacturing processes. In the present invention, the addition of other alloying elements other than the above-mentioned alloy composition is not excluded.

[0036] The steel wire having improved drawability according to one embodiment of the present invention may have a carbon content of cementite in perlite of 7 at% or more after drawing.

[0037] In the steel wire before drawing, the carbon content of cementite (Fe_3C) in pearlite is 25 at%, but the carbon content of cementite in pearlite becomes lower than 25 at% through the drawing process. When the carbon content in cementite is less than 7 at%, delamination may occur, so that the carbon content in cementite is limited to 7 at% or more.

[0038] The steel wire with improved drawability according to one embodiment of the present invention satisfies the following Expression (1).

$$(1)\ [TS]+\exp(\varepsilon)*10 < 1500$$

[0039] In Expression (1), [TS] denotes a tensile strength (MPa) of a wire rod before drawing, and ε denotes a drawing strain.

[0040] The drawing strain (ε) is expressed as 2ln(di/df). Here, di denotes an initial diameter of the steel wire before drawing, and df denotes a diameter of the steel wire after drawing.

[0041] The present invention can slow down a decomposition rate of cementite and suppress the occurrence of delamination by controlling the tensile strength and drawing strain of the wire rod so that the value of Expression (1) is less than 1,500. In general, when excessive drawing strain is applied in the drawing process, carbon present in cementite is released into ferrite, which rapidly reduces the plastic deformability of ferrite, to cause cracks and increase the possibility of delamination, but when the tensile strength of the wire rod is reduced to satisfy Expression (1), the cementite decomposition rate can slow down even at a high drawing strain, and thus delamination can be suppressed.

[0042] Specifically, the case where the drawing strain is 3.0 or more is considered excessive deformation when drawing is performed, but in the present invention, even when a severe drawing strain of 4.02 is applied during drawing, it is possible to provide a steel wire having a torsion number of 27 or more and having ultra-high strength. The ultra-high strength steel wire with an increased drawing limit of the present invention can be applied to products such as tire cord, saw wire, wire rope, piano wire, and steel wire for bridges.

[0043] The tensile strength of the wire rod according to the present invention may be in the range of 700 to 1,000 MPa.

[0044] Next, a method for manufacturing a steel wire with improved drawability according to one embodiment of the present invention will be described.

[0045] A method for manufacturing a steel wire with improved drawability according to one embodiment of the present invention includes: hot-rolling a billet including, in weight percent, C: 0.52 to 0.69%, Mn: 0.3 to 0.8%, Si: 0.1 to 0.5%, a balance of Fe, and unavoidable impurities to obtain a wire rod; cooling the hot-rolled wire rod at a cooling rate of 3 to 20 °C/s; and obtaining a steel wire by drawing the cooled wire rod to satisfy the following Expression (1).

$$(1)\ [TS]+\exp(\varepsilon)*10 < 1500$$

[0046] In Expression (1), [TS] denotes a tensile strength (MPa) of a wire rod before drawing, and ε denotes a drawing strain.

[0047] The steel wire with improved drawability according to the present invention can be manufactured by hot-rolling a billet including the alloy composition described above to obtain a wire rod, cooling the hot-rolled wire rod, and drawing the cooled wire rod to satisfy Expression (1).

[0048] At this time, the billet can be hot-rolled at a temperature range of 800 °C to 1200 °C after heating to a temperature range of 900 to 1100 °C

[0049] At this time, cooling of the wire rod may be performed at a cooling rate of 3 to 20 °C/s. When the cooling rate is less than 3 °C/s, there is a problem that segmented and coarse pearlite is generated, and when the cooling rate exceeds 20 °C/s, there is a problem in that a low temperature structure such as martensite is caused. Therefore, in the present invention, it is preferable to control the cooling rate of the wire rod to 3 to 20 °C/s.

[0050] Subsequently, the cooled wire rod may be drawn to satisfy the above-described Expression (1).

[0051] Hereinafter, the present invention will be described in more detail with reference to preferred examples. However, the following examples are only examples for explaining the present invention in detail, and do not limit the scope of the present invention.

EXAMPLES

[0052] After hot-rolling a billet having an alloy composition and a component range including, in weight percent, C: 0.57 to 0.67%, Mn: 0.3 to 0.8%, Si: 1.0 to 1.6%, a balance of Fe, and other unavoidable impurities, cooling was performed at a cooling rate of 17 °C/s in Inventive Examples 1 to 3, and cooling at a cooling rate of 5 °C/s in Inventive Examples 5 and 6 and Comparative Example 1 to obtain wire rods, and then for Inventive Examples 1 to 5 and Comparative Example 1 in Table 1 below, steel wires were manufactured by drawing according to conditions of a carbon content of cementite, a wire rod strength, and a drawing strain in Table 1 below. Table 1 below shows a torsion number of each steel wire manufactured as described above and whether delamination occurred.

[0053] The torsion number of the steel wire was determined by the number of turns until the steel wire broke during a torsion test applying transverse stress, and the presence or absence of delamination was indicated by checking whether a spiral fracture defect appeared at a wire fracture portion.

[Table 1]

Classification	Wire rod strength (MPa)	Drawing strain	Carbon content of cementite (at%)	Torsion number	Delamination Occurred or not	Value of Expression (1)
Inventive Example 1	856	3.57	12	36	Did not occur	1211
Inventive Example 2	844	3.79	11	34	Did not occur	1287
Inventive Example 3	848	4.02	9	30	Did not occur	1405
Inventive Example 4	948	3.57	10	35	Did not occur	1303
Inventive Example 5	950	3.79	9	33	Did not occur	1393
Comparative Example 1	967	4.02	6	24	Occurred	1524

[0054] As shown in Table 1, it can be confirmed that Inventive Examples 1 to 5 manufactured under the carbon content of cementite and drawing conditions consistent with the present invention not only had an excellent torsion number of 30 or more, but also delamination did not occur. Specifically, in the case of Comparative Example 1 in which the carbon content of cementite in perlite after drawing is 6 at%, and a value of Expression (1) exceeds 1,500, the torsion number was remarkably low at 24, and delamination occurred, but in the case of Inventive Examples 1 to 5 having a carbon content of cementite of 9 at% or more and a value of Expression (1) of less than 1,500, the torsion number was 30 or more and delamination did not occur. It can be confirmed that as the drawing strain increases, the possibility of delamination increases, but when comparing Inventive Example 3 and Comparative Example 1, even though Inventive Example 3 had the same drawing strain as Comparative Example 1, the tensile strength of a wire rod was reduced by 119 MPa, thereby securing a torsion number of 30 or more, and suppressing delamination.

[0055] In the foregoing, although exemplary embodiments of the present invention have been described, the present invention is not limited thereto, and those skilled in the art will be able to understand that various changes and modifications are possible without departing from the concept and scope of the claims described below.

[Industrial Applicability]

[0056] According to one embodiment of the present invention, it is possible to provide a steel wire with improved drawability by controlling the strength of a wire rod and slowing down a decomposition rate of cementite, and a method for manufacturing the same.

Claims

1. A steel wire with improved drawability, which comprises, in weight percent, C: 0.52 to 0.69%, Mn: 0.3 to 0.8%, Si:

0.1 to 0.5%, a balance of Fe, and unavoidable impurities, has a carbon content of cementite in pearlite of 7 at% or more, and satisfies the following Expression (1),

$$(1)\ TS+\exp(\varepsilon)*10 < 1500$$

In Expression (1), TS denotes a tensile strength (MPa) of a wire rod before drawing, and ε denotes a drawing strain.

2. The steel wire of claim 1, wherein the wire rod has a tensile strength of 700 to 1,000 MPa before the drawing.

3. The steel wire of claim 1, wherein the torsion number of the steel wire is 27 or more.

4. The steel wire of claim 1, wherein delamination does not occur at a drawing strain of 4.02 or less.

5. A method for manufacturing a steel wire with improved drawability, comprising:

hot-rolling a billet comprising, in weight percent, C: 0.52 to 0.69%, Mn: 0.3 to 0.8%, Si: 0.1 to 0.5%, a balance of Fe, and unavoidable impurities to obtain a wire rod;
cooling the hot-rolled wire rod at a cooling rate of 3 to 20 °C/s; and
obtaining a steel wire by drawing the cooled wire rod to satisfy the following Expression (1),

$$(1)\ [TS]+\exp(\varepsilon)*10 < 1500$$

In Expression (1), [TS] denotes a tensile strength (MPa) of a wire rod before drawing, and ε denotes a drawing strain.

6. The method of claim 5, wherein delamination does not occur at a wire strain rate of 4.02 or less during the drawing.

INTERNATIONAL SEARCH REPORT

International application No. **PCT/KR2021/016988**

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/02(2006.01)i; **C22C 38/04**(2006.01)i; **C21D 9/52**(2006.01)i; **C21D 8/06**(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 38/02(2006.01); C21D 8/06(2006.01); C21D 9/46(2006.01); C22C 38/00(2006.01); C22C 38/06(2006.01); C22C 38/18(2006.01); C22C 38/60(2006.01); C23C 14/35(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: 가공성(machinability), 펄라이트(pearlite), 시멘타이트(cementite), 탄소(carbon), 열간압연(hot rolled), 변형(strain), 인장강도(tensile strength)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 10-0651302 B1 (KABUSHIKI KAISHA KOBE SEIKO SHO (KOBE STEEL, LTD.)) 29 November 2006 (2006-11-29) See paragraphs [0083]-[0086] and [0114], claim 1 and tables 2-3.	1-6
A	KR 10-2013-0099668 A (POSCO) 06 September 2013 (2013-09-06) See paragraph [0051] and claim 2.	1-6
A	JP 2000-001751 A (NIPPON STEEL CORP.) 07 January 2000 (2000-01-07) See paragraph [0032], claim 1 and table 2.	1-6
A	JP 2012-126954 A (KOBE STEEL LTD.) 05 July 2012 (2012-07-05) See claims 1-2.	1-6
A	US 2017-0121786 A1 (JFE STEEL CORPORATION) 04 May 2017 (2017-05-04) See claims 1 and 4 and table 2.	1-6

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

Date of the actual completion of the international search	Date of mailing of the international search report
25 February 2022	**02 March 2022**

Name and mailing address of the ISA/KR	Authorized officer
Korean Intellectual Property Office **Government Complex-Daejeon Building 4, 189 Cheongsa-ro, Seo-gu, Daejeon 35208**	
Facsimile No. **+82-42-481-8578**	Telephone No.

Form PCT/ISA/210 (second sheet) (July 2019)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2021/016988

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
KR 10-0651302 B1	29 November 2006	BR PI0500201 A	06 September 2005
		BR PI0500201 B1	30 December 2014
		EP 1559805 A1	03 August 2005
		EP 1559805 B1	23 March 2011
		JP 2005-206853 A	04 August 2005
		KR 10-2005-0076674 A	26 July 2005
		US 2005-0155672 A1	21 July 2005
		US 7393422 B2	01 July 2008
KR 10-2013-0099668 A	06 September 2013	KR 10-1316154 B1	08 October 2013
JP 2000-001751 A	07 January 2000	None	
JP 2012-126954 A	05 July 2012	JP 5503515 B2	28 May 2014
US 2017-0121786 A1	04 May 2017	CN 106133169 A	16 November 2016
		CN 106133169 B	05 January 2018
		EP 3091097 A1	09 November 2016
		EP 3091097 B1	17 October 2018
		JP 6065121 B2	25 January 2017
		JP WO2015-146174 A1	13 April 2017
		KR 10-1892526 B1	28 August 2018
		KR 10-2016-0138231 A	02 December 2016
		TW 201538745 A	16 October 2015
		TW I544086 B	01 August 2016
		US 10844454 B2	24 November 2020
		WO 2015-146174 A1	01 October 2015

Form PCT/ISA/210 (patent family annex) (July 2019)