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(54) **HIGH-STRENGTH STEEL WIRE AND METHOD OF MANUFACTURING THE SAME**

HOCHFESTER STAHLDRAHT UND VERFAHREN ZUR HERSTELLUNG DESSELBEN

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Description

CROSS-REFERENCE TO RELATED APPLICATION(S)

BACKGROUND

1. FIELD

[0001] The present disclosure relates to a high-strength steel wire and a method of manufacturing the high-strength steel wire.

2. DESCRIPTION OF RELATED ART

[0002] Pearlite steel wires produced through a cold drawing process have good mechanical characteristics with an appropriate degree of ductility in combination therewith, and are widely used as one of the highest-strength steel materials known, in applications such as tire cords and bridge cables.

[0003] The strength of pearlite steel wires is markedly increased after a drawing process, and it is known that this is due to a decrease in lamellar spacing. To date, such behaviors related to the microstructures of pearlite steel wires have been widely studied.

[0004] For example, the results of experiments performed using devices or methods such as Mossbauer spectroscopy, electron energy loss spectroscopy (EELS), 3-dimensional atom probe (3D-AP: an analysis method enabling atomic-level quantitative analysis and 3-dimensional imaging) have shown that cementite included in pearlite is at least partially decomposed during a cold drawing process.

[0005] Such decomposition of cementite has a strong effect on deformation mechanisms including the formation and mobility of dislocations during a drawing process, and as a result has a significant effect on mechanical characteristics. Therefore, the decomposition of cementite is still being studied as an important subject by many researchers.

[0006] However, the effects of alloying elements on the decomposition of cementite have not yet been studied in detail, and thus have not yet been known in relation to mechanical characteristics.

[0007] In addition, the strength and ductility of pearlite steel wires may be more effectively improved by appropriately controlling the decomposition behaviors of cementite, and thus technical research relating to this issue is required.

KR 2016 0075956 A relates to a high strength steel wire and a manufacturing method thereof . More specifically, the steel wire comprises: carbon (C), manganese (Mn), silicon (Si), nickel (Ni), iron (Fe) and unavoidable impurities. The high strength steel wire has 17% at. % or less of carbon content in a pearlite phase of the steel wire.

JP 2004 360005 A relates to a steel wire with delayed fracture properties, having a composition comprising by weight, 0.6-1.2% C, 0.12-2% Si, 0.3-1.0% Mn, ≤0.025% P and ≤0.0025% S, and if required, further comprising one of Al, Cr, Mo, Ni, Cu, V, Nb, W, Ti and B, the balance being iron and unavoidable impurities.

SUMMARY

[0008] Aspects of the present disclosure provide a high-strength steel wire configured to have markedly increased tensile strength after a drawing process, and a method of manufacturing the high-strength steel wire.

[0009] According to an aspect of the present disclosure, a high-strength steel wire includes, by wt%, carbon (C): 0.52% to 0.72%, manganese (Mn): 0.6% to 0.8%, silicon (Si): 0.1% to 0.4%, nickel (Ni): 0.3% to 1.2%, vanadium (V): 0.3% to 1.2%, and a balance of iron (Fe) and inevitable impurities, wherein after a drawing process, the high-strength steel wire has a carbon content of 20 at.% or less in cementite within pearlite,

> wherein the high-strength steel wire has a pearlite lamellar spacing of 180 nm or less, and
> wherein the high-strength steel wire has a tensile strength of 1450 MPa or greater and an elongation of 13% or greater.

[0010] According to another aspect of the present disclosure, a method of manufacturing a high-strength steel wire as defined in the foregoing includes: heating a steel billet satisfying the above-described alloying composition; finish hot rolling the heated steel billet at a temperature of 900°C to 1200°C to manufacture a wire rod; cooling the wire rod to room temperature at a cooling rate of 5°C/s to 20°C/s; and drawing the cooled wire rod to manufacture a steel wire, wherein the steel wire has a carbon content of 20 at.% or less in cementite within pearlite and wherein the drawing is performed at a strain (ε) of 60% to 90%.

DETAILED DESCRIPTION

[0011] When a wire rod having pearlite in the microstructure thereof is subjected to a drawing process, cementite included in pearlite deforms plastically, and in addition thereto, carbon separates from the cementite and stabilizes while adhering to lower sides of ferrite dislocations. At this time, carbon adhered to dislocations lowers mobility, and thus the yield strength of the wire rod increases.

[0012] Along with this, nickel (Ni) and vanadium (V) are added to steel according to the present disclosure as alloying elements, and since nickel (Ni) and vanadium (V) facilitate the decomposition of cementite, the amount of carbon (C) moving into ferrite increases, even with the same amount of drawing, thereby proving a high-strength steel wire.

[0013] Specifically, according to an aspect of the present disclosure, a high-strength steel wire includes, by wt%, carbon (C) : 0.52% to 0.72%, manganese (Mn): 0.6% to 0.8%, silicon (Si): 0.1% to 0.4%, nickel (Ni): 0.3% to 1.2%, and vanadium (V): 0.3% to 1.2%.

[0014] In the following description, reasons for adjusting the alloying composition of the high-strength steel wire as described above will be described in detail. In the following description, the content of each element is given in wt%, unless otherwise specified.

Carbon (C): 0.52% to 0.72%

[0015] Carbon (C) is a key element guaranteeing strength. However, if the content of carbon (C) in steel is excessively high, the area reduction ratio of a steel material may be decreased, and thus, a strength improving effect may not be obtained through a drawing process. In addition, if the content of carbon (C) is excessively low, a desired degree of strength may not be obtained.

[0016] Therefore, according to the present disclosure, it is necessary to adjust the content of carbon (C) to be within the range of 0.52% to 0.72%. More preferably, the content of carbon (C) may be adjusted to be within the range of 0.55% to 0.70%.

Manganese (Mn): 0.6% to 0.8%

[0017] Manganese (Mn) excessively segregates along a centreline. If the content of manganese (Mn) is greater than 0.8%, a low-temperature microstructure may very likely be formed, and thus it is necessary that the content of manganese (Mn) is adjusted to be 0.8% or less. However, if the content of manganese (Mn) is excessively low, less than 0.6%, it is difficult to guarantee hardenability.

[0018] Therefore, according to the present disclosure, it is necessary to adjust the content of manganese (Mn) to be within the range of 0.6% to 0.8%. More preferably, the content of manganese (Mn) may be adjusted to be within the range of 0.65% to 0.75%.

Silicon (Si): 0.1% to 0.4%

[0019] Silicon (Si) is effective in improving strength because silicon (Si) preferentially dissolves in ferrite. To this end, it is necessary that silicon (Si) is added in an amount of 0.1% or greater. However, if the content of silicon (Si) is excessively high, greater than 0.4%, the ductility of steel may be reduced.

[0020] Therefore, according to the present disclosure, it is necessary to adjust the content of silicon (Si) to be within the range of 0.1% to 0.4%. More preferably, the content of silicon (Si) may be adjusted to be within the range of 0.15% to 0.30%.

Nickel (Ni): 0.3% to 1.2%

[0021] Nickel (Ni) has a function of facilitating the decomposition of cementite by causing interfaces of pearlite lamellae to become unstable, and a function of improving plastic deformability by increasing the number of operable slip systems of cementite in pearlite.

[0022] To sufficiently obtain these effects, it is necessary that the content of nickel (Ni) is 0.3% or greater. However, since nickel (Ni) is a relatively expensive element, when production costs are considered, it is necessary that the content of nickel (Ni) is adjusted to be 1.2% or less.

[0023] Therefore, according to the present disclosure, it is necessary to adjust the content of nickel (Ni) to be within the range of 0.3% to 1.2%. More preferably, the content of nickel (Ni) may be adjusted to be within the range of 0.5% to 1.0%.

Vanadium (V): 0.3% to 1.2%

[0024] Vanadium (V) is an element precipitating in steel in the form of vanadium carbide (VC) and thus improving strength. In the present disclosure, together with nickel (Ni), vanadium (V) causes interfaces of pearlite lamellae to become unstable, thereby facilitating the decomposition of cementite.
[0025] To sufficiently obtain such effects, it is necessary to add vanadium in an amount of 0.3% or greater. However, if the content of vanadium (V) is greater than 1.2%, ductility may sharply decrease due to clumping of precipitate particles, and thus drawability may deteriorate.
[0026] Therefore, according to the present disclosure, it is necessary to adjust the content of vanadium (V) to be within the range of 0.3% to 1.2%. More preferably, the content of vanadium (V) may be adjusted to be within the range of 0.4% to 1.0%.
[0027] The other component of the high-strength steel wire of the present disclosure is iron (Fe). However, impurities of raw materials or in manufacturing environments may be inevitably included in the high-strength steel wire , and such impurities may not be removed from the high-strength steel wire. Such impurities are well-known to those of ordinary skill in manufacturing industries, and thus specific descriptions of the impurities will not be given in the present disclosure.
[0028] In the steel wire of the present disclosure, satisfying the above-described alloying composition, the carbon content of cementite included in pearlite is 20 at.% or less.
[0029] In general, since cementite consists of three iron (Fe)atoms and one carbon (C) atom, the carbon content of cementite (Fe_3C) included in pearlite is 25 at. % before a drawing process. However, as a drawing process is performed, the carbon content of cementite included in pearlite decreases below 25 at.%, and this means that cementite included in pearlite is plastically deformed and also decomposed by the drawing process . This decomposition of cementite occurs because a stable energy state is achieved when carbon separates from cementite and moves into a ferrite matrix.
[0030] As described above, when a drawing process is performed on the steel wire of the present disclosure, including nickel (Ni) and vanadium (V), the decomposition of cementite effectively occurs, and thus the carbon content of cementite included in pearlite becomes 20 at.% or less in the steel wire.
[0031] As described above, since solid-solution strengthening is obtained as carbon separates from cementite and moves into ferrite, the steel wire of the present disclosure has a tensile strength of 1450 MPa or greater and an elongation of 13% or greater.
[0032] In addition, the steel wire of the present disclosure has a pearlite lamellar spacing of 180 nm or less. If the pearlite lamellar spacing is greater than 180 nm, the strength and ductility of the steel wire decrease as the pearlite lamellar spacing increases. Since the steel wire is required to have a smaller pearlite lamellar spacing, the lower limit of the pearlite lamellar spacing is not specifically set.
[0033] Hereinafter, a method of manufacturing a high-strength steel wire in accordance with the foregoing will be described in detail as another aspect of the present disclosure.
[0034] According to the present disclosure, a steel wire is manufactured by manufacturing a wire rod having the above-described alloying composition and performing a drawing process on the wire rod.
[0035] The wire rod may be manufactured using various rod manufacturing methods generally known in the art. However, the wire rod may be manufactured through a series of processes to be described below.
[0036] First, a steel billet having the above-described alloying composition is manufactured, and the steel billet is heated to within austenite temperature range. Then, a hot rolling process is performed on the steel billet to form a wire rod.
[0037] In the hot rolling process, it is necessary that finish hot rolling be performed at a temperature of 900°C to 1200°C. If the temperature of finish hot rolling is lower than 900°C, the lifespan of rolls may decrease due to a large rolling load. Conversely, if the temperature of finish hot rolling is higher than 1200°C, the size of grains may increase to cause a decrease in ductility, and decarbonization may occur excessively, leading to a deterioration in drawability.
[0038] After the finish hot rolling, it is necessary that the wire rod be cooled to room temperature at a cooling rate of 5°C/s to 20°C/s.
[0039] If the wire rod is cooled at a cooling rate lower than 5°C/s, drawability may deteriorate because of the formation of pro-eutectoid ferrite, and if the wire rod is cooled at a cooling rate higher than 20°C/s, a low-temperature microstructure may be formed.
[0040] A steel wire is manufactured by performing a drawing process on the cooled wire rod at a strain (ε) of 60% to 90%.
[0041] In this case, if the strain is less than 60%, it may be difficult to obtain a sufficient degree of strength, and if the strain is greater than 90%, delamination may occur and thus, the possibility of product defects may increase.
[0042] The steel wire of the present disclosure obtained through the drawing process has a carbon content of 20 at.% or less in cementite within pearlite, a tensile strength of 1450 MPa or greater, and an elongation of 13% or greater.
[0043] Hereinafter, the present disclosure will be described more specifically through examples. However, the following examples should be considered in a descriptive sense only and rather than for the purposes of limitation. The scope of the present invention is defined by the appended claims.

(Examples)

[0044] Steel billets having compositions as shown in Table 1 below were prepared, and wire rods were manufactured by hot rolling and cooling the steel billets under the conditions shown in Table 1 below. Thereafter, a drawing process was performed on each of the wire rods, and the drawn wire rods were rolled to be plate shaped to manufacture steel wires.

[0045] The carbon content of cementite in pearlite, tensile characteristics, and lamellar spacing of each of the steel wires were measured, and results of the measurement are shown in Table 2 below.

[Table 1]

No.	Alloying Composition (wt%)					Manufacturing Conditions		
	C	Si	Mn	Ni	V	Finish hot Rolling Temperature (°C)	Cooling Rate (°C/s)	Strain (ε)
Inventive Steel 1	0.62	0.2	0.7	0.6	0.5	900	9	81
Inventive Steel 2	0.62	0.2	0.7	1.0	1.0	900	10	81
Comparative Steel 1	0.62	0.2	0.7	0	0	830	11	81
Comparative Steel 2	0.62	0.2	0.7	0.1	0.1	830	12	81
Comparative Steel 3	0.62	0.2	0.7	0.1	2.0	830	11	81

[Table 2]

No.	Microstructure		Tensile characteristics	
	Carbon Content (at.%)	Lamellar Spacing (nm)	Tensile Strength (MPa)	Elongation (%)
Inventive Steel 1	19	168	1492	13.7
Inventive Steel 2	17	147	1532	14.2
Comparative Steel 1	23	201	1429	12.4
Comparative Steel 2	22	199	1423	12.5
Comparative Steel 3	21	183	1285	8.1
(In Table 2, carbon content refers to the carbon content of cementite in pearlite after the drawing process.)				

[0046] As shown in Tables 1 and 2, Inventive Steel 1 further included 0.6 wt% nickel (Ni) and 0.5 wt% vanadium (V) when compared to Comparative Steel 1, and after the drawing process, the content of carbon in cementite of Inventive Steel 1 decreased to 19 at.%.

[0047] As mentioned above, since the carbon content of cementite in pearlite was lower in Inventive Steel 1 than in Comparative Steel 1, decomposition of cementite occurred relatively rapidly in Inventive Steel 1 when the same amount of deformation was applied. Since carbon atoms separated as a result of cementite decomposition and dissolved in ferrite, a tensile strength increase of 63 MPa from 1429 MPa to 1492 was obtained. In addition, although the strength of Inventive Steel 1 was increased, the elongation of Inventive Steel 1 was 13.7%, higher than that of Comparative Steel 1. This shows that the addition of nickel (Ni) and vanadium (V) improves ductility in addition to increasing strength.

[0048] In addition, Inventive Steel 2, further including 1.0 wt% nickel (Ni) and 1.0 wt% vanadium (V), as compared to Comparative Steel 1, had a carbon content of 17 at. % in cementite within pearlite which was much lower than that of Comparative Steel 1. Owing to this, Inventive Steel 2 had a tensile strength of 1532 MPa and an elongation of 14.2% which were much higher than those of Comparative Steel 1.

[0049] The carbon content of cementite in pearlite of each of Comparative Steels 2 and 3 to which nickel (Ni) and vanadium (V) were added in excessively small or large amounts was lower than that of Comparative Steel 1 but did not decrease to the degree of the present disclosure. Thus, the strength and elongation of Comparative Steels 2 and 3 were lower than those of Inventive Steels 1 and 2.

[0050] According to the present disclosure, nickel (Ni) and vanadium (V) are added together in appropriate amounts, and thus, lamellar spacing is decreased. This affects the strength and ductility of steel.

[0051] Therefore, according to the present disclosure, a steel wire having high strength and ductility is provided.

[0052] According to the present disclosure, nickel (Ni) and vanadium (V) are added as alloying elements to effectively facilitate the decomposition of cementite in pearlite after a drawing process, thereby providing a high-strength steel wire having improved tensile strength.

[0053] While exemplary embodiments have been shown and 5 described above, 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 steel wire comprising, by wt%, carbon (C) : 0.52% to 0.72%, manganese (Mn) : 0.6% to 0.8%, silicon (Si) : 0.1% to 0.4%, nickel (Ni) : 0.3% to 1.2%, vanadium (V): 0.3% to 1.2%, and a balance of iron (Fe) and inevitable impurities,

   wherein after a drawing process, the high-strength steel wire has a carbon content of 20 at. % or less in cementite within pearlite,
   wherein the high-strength steel wire has a pearlite lamellar spacing of 180 nm or less, and
   wherein the high-strength steel wire has a tensile strength of 1450 MPa or greater and an elongation of 13% or greater.

2. A method of manufacturing a high-strength steel wire as claimed in Claim 1, the method comprising:

   heating a steel billet comprising, by wt%, carbon (C): 0.52% to 0.72%, manganese (Mn) : 0.6% to 0.8%, silicon (Si) : 0.1% to 0.4%, nickel (Ni) : 0.3% to 1.2%, vanadium (V) : 0.3% to 1.2%, and a balance of iron (Fe) and inevitable impurities;
   finish hot rolling the heated steel billet at a temperature of 900°C to 1200°C to manufacture a wire rod;
   cooling the wire rod to room temperature at a cooling rate of 5°C/s to 20°C/s; and
   drawing the cooled wire rod to manufacture a steel wire,
   wherein the steel wire has a carbon content of 20 at.% or less in cementite within pearlite, and
   wherein the drawing is performed at a strain (ε) of 60% to 90%.

Patentansprüche

1. Hochfester Stahldraht, umfassend in Gew.-% Kohlenstoff (C): 0,52 % bis 0,72 %, Mangan (Mn): 0,6 % bis 0,8 %, Silizium (Si): 0,1 % bis 0,4 %, Nickel (Ni): 0,3 % bis 1,2 %, Vanadium (V): 0,3 % bis 1,2 % und einen Rest an Eisen (Fe) und unvermeidlichen Verunreinigungen,

   wobei der hochfeste Stahldraht nach einem Ziehvorgang einen Kohlenstoffgehalt von 20 Atom- % oder weniger in Zementit innerhalb von Perlit aufweist,
   wobei der hochfeste Stahldraht einen Perlit-Lamellenabstand von 180 nm oder weniger aufweist, und
   wobei der hochfeste Stahldraht eine Zugfestigkeit von 1450 MPa oder mehr und eine Dehnung von 13 % oder mehr aufweist.

2. Verfahren zum Herstellen eines hochfesten Stahldrahts nach Anspruch 1, wobei das Verfahren umfasst:

   Erhitzen eines Stahlknuppels, umfassend in Gew.-% Kohlenstoff (C): 0,52 % bis 0,72 %, Mangan (Mn): 0,6 % bis 0,8 %, Silizium (Si): 0,1 % bis 0,4 %, Nickel (Ni): 0,3 % bis 1,2 %, Vanadium (V): 0,3 % bis 1,2 % und einen Rest an Eisen (Fe) und unvermeidlichen Verunreinigungen;
   Beenden des Warmwalzens des erhitzten Stahllknuppels bei einer Temperatur von 900 °C bis 1200 °C, um einen Walzdraht herzustellen;
   Abkühlen des Walzdrahts auf Raumtemperatur mit einer Abkühlgeschwindigkeit von 5 °C/s bis 20 °C/s; und
   Ziehen des abgekühlten Walzdrahts zur Herstellung eines Stahldrahts,
   wobei der Stahldraht einen Kohlenstoffgehalt von 20 Atom-% oder weniger in Zementit innerhalb von Perlit aufweist, und
   wobei das Ziehen bei einer Dehnung (ε) von 60 % bis 90 % durchgeführt wird.

Revendications

1. **1.** Fil d'acier à haute résistance composé, en % en poids, de carbone (C) : 0,52 % à 0,72 %, de manganèse (Mn) : 0,6 % à 0,8 %, de silicium (Si) : 0,1 % à 0,4 %, de nickel (Ni) : 0,3 % à 1,2 %, de vanadium (V) : 0,3 % à 1,2 %, et d'un reste constitué de fer (Fe) et d'impuretés inévitables,

   après un processus d'étirage, le fil d'acier à haute résistance possédant une teneur en carbone de 20 à .% ou moins de cémentite dans la perlite,
   le fil d'acier à haute résistance possédant un espacement lamellaire de perlite de 180 nm ou moins, et
   le fil d'acier à haute résistance possédant une résistance à la traction de 1 450 MPa ou plus et un allongement de 13 % ou plus.

2. **2.** Procédé de fabrication d'un fil d'acier à haute résistance selon la revendication 1, le procédé comprenant : le chauffage d'une billette d'acier composé, en % en poids, de carbone (C) :

   0,52 % à 0,72 %, de manganèse (Mn) :
   0,6 % à 0,8 %, de silicium (Si) :
   0,1 % à 0,4 %, de nickel (Ni) :
   0,3 % à 1,2 %, de vanadium (V) :
   0,3 % à 1,2 %, le reste étant constitué de fer (Fe) et d'impuretés inévitables ;

   l'achèvement du laminage à chaud de la billette d'acier chauffée à une température de 900 °C à 1 200 °C pour fabriquer un fil machine ;
   le refroidissement du fil machine à température ambiante à une vitesse de refroidissement de 5 °C/s à 20 °C/s ; et l'étirage du fil machine refroidi pour fabriquer un fil d'acier,
   le fil d'acier possédant une teneur en carbone de 20 à .% ou moins dans la cémentite dans la perlite, et
   l'étirage étant effectué sous une contrainte (ε) de 60 % à 90 %.

REFERENCES CITED IN THE DESCRIPTION

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