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(54) **CALCIUM-CONTAINING GRAPHITE STEEL HAVING EXCELLENT MACHINABILITY, AND MANUFACTURING METHOD THEREFOR**

(57) The present invention relates to a graphite steel having excellent machinability, and a manufacturing method therefor, and more specifically, to a calcium-containing graphite steel having machinability superior to that of normal free-cutting steel and a manufacturing method therefor.

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Description

[Technical Field]

5 **[0001]** The present disclosure relates to a graphite steel having excellent machinability and a manufacturing method therefor, and more particularly, to a calcium-containing graphite steel having machinability superior to that of normal free-cutting steel and a manufacturing method therefor.

[Background Art]

10 **[0002]** In general, free-cutting steels to which machinability-imparting elements such as Pb and Bi are added have been used as a material for mechanical parts that require machinability. In order to improve machinability of steel materials, liquid metal embrittlement may be used by adding low-melting point machinability-imparting elements such as Pb and Bi to steel, or a large amount of MnS may be formed in steel. Such free-cutting steels have excellent machinability of steels such as surface roughness, chip controllability, and tool life during cutting.

15 **[0003]** However, Pb-added free-cutting steel, which is generally known to have excellent machinability, is very harmful to the human body because harmful substances such as toxic fume are emitted during a cutting process and causes a problem in recycling of steel materials. Therefore, addition of S, Bi, Te, Sn, and the like is suggested for replacement thereof. However, it has been known that many problems may be caused thereby, for example, cracks easily occur while manufacturing steel materials causing considerable difficulties in production or cracks may occur during hot rolling.

20 **[0004]** Free-cutting steel developed to solve the above-described problems is graphite steel. Graphite steel, as a steel containing fine graphite grains inside a ferrite matrix or a pearlite matrix, has excellent machinability because fine graphite grains contained therein serve as a crack source during cutting, acting as a chip breaker.

25 **[0005]** However, despite these advantages of graphite steel, graphite steel has not been commercialized currently. When carbon is added to steel, graphite, even a stable phase, precipitates as cementite that is a metastable phase, so that it is difficult to precipitate graphite without a separate long-term heat treatment. During such a long-term heat treatment process, decarburization occurs, causing adverse effects on performance of final products.

30 **[0006]** In addition, although graphite grains are precipitated by graphitization heat treatment, in the case where the graphite grains are non-uniformly distributed in irregular shapes, physical properties are non-uniformly distributed during cutting to considerably deteriorate chip controllability or surface roughness and shorten tool life, making it difficult to obtain advantages of graphite steel. Therefore, there is a need to provide a method for manufacturing a graphite free-cutting steel having excellent machinability by using MnS inclusions together with graphite grains.

[0007] (Related Art Document) Patent Document 1: Korean Patent Application Publication No. 10-2015-0057400

[Disclosure]

[Technical Problem]

40 **[0008]** Provided are a calcium-containing graphite steel having excellent machinability and a manufacturing method therefor.

[0009] However, the technical problems to be solved by the present disclosure are not limited to the aforementioned problems, and any other technical problems not mentioned herein will be clearly understood from the following description by those skilled in the art to which the present disclosure pertains.

[Technical Solution]

50 **[0010]** In accordance with an aspect of the present disclosure to achieve the above-described objects, a graphite steel includes, in percent by weight (wt%), 0.60 to 0.90% of carbon (C), 2.0 to 2.5% of silicon (Si), 0.7 to 1.3% of manganese (Mn), 0.2 to 0.5% of sulfur (S), 0.01 to 0.05% of aluminum (Al), 0.005 to 0.020% of titanium (Ti), 0.003 to 0.015% of nitrogen (N), 0.0001 to 0.050% of calcium (Ca), and the balance of iron (Fe) and inevitable impurities, wherein the graphite steel includes a microstructure in which graphite grains are distributed in a ferrite matrix, has a graphitization rate of 95% or more, and includes a total of 5 wt% or less of MnS inclusions and pearlite.

55 **[0011]** In accordance with another aspect of the present disclosure, a method for manufacturing a graphite steel includes: preparing a billet including, in percent by weight (wt%), 0.60 to 0.90% of carbon (C), 2.0 to 2.5% of silicon (Si), 0.7 to 1.3% of manganese (Mn), 0.2 to 0.5% of sulfur (S), 0.01 to 0.05% of aluminum (Al), 0.005 to 0.020% of titanium (Ti), 0.003 to 0.015% of nitrogen (N), 0.0001 to 0.050% of calcium (Ca), and the balance of iron (Fe) and inevitable impurities; hot rolling the billet to prepare a wire rod; and performing graphitizing heat treatment on the prepared wire rod.

[Advantageous Effects]

[0012] Since the graphite steel according to the present disclosure includes calcium (Ca), a Ca-Al-based oxide acting as a nucleus of graphitization is formed to promote graphitization and a Ca-based emulsion is formed to improve machinability. The present disclosure may provide a graphite steel having excellent machinability and capable of replacing conventional free-cutting steels and a manufacturing method therefor.

[0013] The graphite steel according to the present disclosure having excellent machinability may replace conventional free-cutting steel materials, and thus eco-friendly graphite free-cutting steel from which harmful elements such as Pb and Bi are replaced may be provided.

[Best Mode]

[0014] A graphite steel according to an embodiment of the present disclosure includes, in percent by weight (wt%), 0.60 to 0.90% of carbon (C), 2.0 to 2.5% of silicon (Si), 0.7 to 1.3% of manganese (Mn), 0.2 to 0.5% of sulfur (S), 0.01 to 0.05% of aluminum (Al), 0.005 to 0.020% of titanium (Ti), 0.0030 to 0.0150% of nitrogen (N), 0.0001 to 0.050% of calcium (Ca), and the balance of iron (Fe) and inevitable impurities, wherein the graphite steel includes a microstructure in which graphite grains are distributed in a ferrite matrix, has a graphitization rate of 95% or more, and includes a total of 5 wt% or less of MnS inclusions and pearlite.

[Modes of the Invention]

[0015] Hereinafter, preferred embodiments of the present disclosure will now be described. However, the present disclosure may be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein. In addition, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the disclosure to those skilled in the art.

[0016] The terms used herein are merely used to describe particular embodiments. Thus, an expression used in the singular encompasses the expression of the plural, unless it has a clearly different meaning in the context.

[0017] Hereinafter, the unit is wt% unless otherwise stated. In addition, it is to be understood that the terms such as "including" or "having" are intended to indicate the existence of components disclosed in the specification, and are not intended to preclude the possibility that one or more other components may exist or may be added.

[0018] Meanwhile, unless otherwise defined, all terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. Thus, these terms should not be interpreted in an idealized or overly formal sense unless expressly so defined herein. As used herein, the singular forms are intended to include the plural forms as well, unless the context clearly indicates otherwise.

[0019] In addition, the terms "about", "substantially", etc. used throughout the specification mean that when a natural manufacturing and substance allowable error are suggested, such an allowable error corresponds a value or is similar to the value, and such values are intended for the sake of clear understanding of the present invention or to prevent an unconscious infringer from illegally using the disclosure of the present invention.

[0020] Hereinafter, a graphite steel having excellent machinability and a manufacturing method therefor according to the present disclosure will be described in detail.

[Graphite Steel]

[0021] A graphite steel according to an embodiment of the present disclosure may include, in percent by weight (wt%), 0.60 to 0.90% of carbon (C), 2.0 to 2.5% of silicon (Si), 0.7 to 1.3% of manganese (Mn), 0.2 to 0.5% of sulfur (S), 0.01 to 0.05% of aluminum (Al), 0.005 to 0.020% of titanium (Ti), 0.003 to 0.015% of nitrogen (N), 0.0001 to 0.050% of calcium (Ca), and the balance of iron (Fe) and inevitable impurities.

[Composition]

Carbon (C): 0.60 to 0.90 wt%

[0022] Carbon is an essential element to form graphite grains. If the C content is less than 0.60 wt%, the effect of improving machinability is insufficient and distribution of graphite is non-uniform even after graphitization is completed. On the contrary, if the C content is excessive exceeding 0.90 wt%, coarse graphite grains are formed and the aspect ratio increases, so that machinability, particularly, surface roughness, may deteriorate. Therefore, an upper limit of the C content may be controlled to 0.90 wt%.

Silicon (Si): 2.0 to 2.5 wt%

[0023] Silicon is an essential component, as a deoxidizer, to prepare molten steel and is a graphitization-promoting element allowing carbon to precipitate into graphite by destabilizing cementite contained in steel, and thus it is preferable to necessarily include silicon. In order to achieve these effects in the present disclosure, the Si content may be 2.0 wt%.

[0024] However, if the Si content is excessive, the effects may be saturated, and hardness also increases due to solid solution strengthening effect to accelerate tool wear during cutting, embrittlement is caused by an increase in non-metallic inclusions, and excessive decarburization may occur during hot rolling. Therefore, an upper limit of the Si content may be controlled to 2.5 wt%.

Manganese (Mn): 0.7 to 1.3 wt%

[0025] Manganese improves strength and impact properties of steel materials and combines with sulfur contained in steel to form MnS inclusions contributing to improvement of machinability. In order to achieve these effects in the present disclosure, the Mn content may be 0.7 wt% or more.

[0026] On the contrary, an excessive Mn content may inhibit graphitization to delay graphitization completion time and may increase strength and hardness to deteriorate machinability. Therefore, an upper limit of the Mn content may be 1.3 wt%.

Sulfur (S): 0.2 to 0.5 wt%

[0027] Sulfur combines with manganese to form MnS inclusions and machinability may be improved as the MnS inclusions are formed. However, if the S content is excessive, graphitization of carbon in steel may be inhibited, S may be segregated into crystal grains to deteriorate toughness, a low-melting point emulsion may be formed to impair hot rollability, and mechanical anisotropy may be observed due to MnS stretched by rolling. Therefore, in the present disclosure, formation of MnS inclusions may be induced by adjusting the S content within a range capable of contributing to improvement of machinability without causing mechanical anisotropy.

[0028] Therefore, if the S content is controlled to less than 0.2 wt%, MnS inclusions cannot be formed in a fraction sufficient to improve machinability. In addition, if the S content exceeds 0.5 wt%, anisotropy of a material increases to cause breakage during cutting so that risks may occur during processing.

Aluminum (Al): 0.01 to 0.05 wt%

[0029] Aluminum is the second most important material to promote graphitization after silicon. This is because aluminum, when existing as a solid solution of Al, destabilizes cementite, and thus Al needs to exist as a solid solution. In the present disclosure, Al may be contained in an amount of 0.01 wt% or more to obtain such effects.

[0030] However, if the Al content is excessive, not only the effects may be saturated but also nozzle clogging may be induced during continuous casting and AlN may be formed in austenite grain boundaries causing non-uniform distribution of graphite including AlN as nuclei in the grain boundaries. Therefore, an upper limit of the Al content may be controlled to 0.05 wt%.

Titanium (Ti): 0.005 to 0.020 wt%

[0031] Titanium, like aluminum, combines with nitrogen to form nitrides such as TiN and AlN, and these nitrides act as nuclei for graphite formation during constant-temperature heat treatment.

[0032] While AlN that is formed at a low temperature non-uniformly precipitates after austenite is formed, TiN that is formed at a temperature higher than that of AlN is crystallized before formation of austenite is completed and thus uniformly distributed in the austenite grain boundaries and in the grains. Therefore, graphite grains formed of TiN as nuclei are also distributed finely and uniformly.

[0033] Although the Ti content may be 0.005 wt% or more to obtain these effects, addition of Ti in an amount greater than 0.02 wt% may cause consumption of carbon required for forming graphite by forming coarse carbonitrides, thereby deteriorating graphitization. Therefore, an upper limit of the Ti content may be controlled to 0.020 wt%.

Nitrogen (N): 0.003 to 0.015 wt%

[0034] Nitrogen combines with titanium and aluminum to form TiN, AlN, and the like, and nitrides such as AlN are mainly formed in austenite grain boundaries. Because graphite is formed using such nitrides as nuclei during graphitizing heat treatment, non-uniform distribution of graphite may be caused thereby, and therefore it is necessary to add an

appropriate amount thereof.

[0035] If the amount of nitrogen added is excessive, nitrogen fails to bind to a nitride-forming element and remains as a solid solution to increase strength and stabilize cementite, thereby adversely affecting to delay graphitization.

[0036] Therefore, a lower limit of the N content may be controlled to 0.003 wt% and an upper limit thereof may be controlled to 0.015 wt% in the present disclosure such that nitrogen is consumed to form nitrides acting as nuclei for forming graphite and does not remain as a solid solution.

Calcium (Ca): 0.0001 to 0.050 wt%

[0037] Calcium forms a Ca-Al-based oxide in steel having the composition of the present disclosure, and the Ca-Al-based oxide may act as a nucleus of graphitization to promote graphitization and may also form a Ca-based emulsion to improve machinability. Stress is concentrated during a cutting process at the interface between the Ca-based emulsion and the matrix structure to form voids which grow and spread to form cracks, exhibiting the effects of being cut and separated as chips in steel.

[0038] The effects are insufficient in the case where the Ca content is less than 0.0001 wt%, and coarse oxide-based non-metal inclusions are produced in a large quantity in the case where the Ca content is greater than 0.050 wt%, thereby deteriorating fatigue strength of mechanical parts. Therefore, the Ca content may be controlled to a range of 0.0001 to 0.050 wt%.

Other components

[0039] The remaining component of the composition of the present disclosure is iron (Fe). However, the composition may include unintended impurities inevitably incorporated from raw materials or surrounding environments in normal manufacturing processes. However, the graphite steel according to the present disclosure may not include phosphorus (P) or oxygen (O). These impurities are not specifically mentioned in the present disclosure, as they are known to any person skilled in the art.

[Microstructure]

[0040] The graphite steel according to the present disclosure has a microstructure in which graphite grains are distributed in a ferrite matrix, has a graphitization rate of 95% or more, and includes a total of 5 wt% or less of MnS inclusions and pearlite.

[0041] The graphite steel according to an embodiment of the present disclosure may have a graphitization rate of 98% or more, more preferably 99% or more, and most preferably 99.5% or more.

[0042] Meanwhile, the graphitization rate refers to a ratio of an amount of carbon existing as a graphite state to an amount of carbon added to steel and is defined by Equation 1 below. A graphitization rate of 95% or more indicates that most carbon added to the steel is consumed to form graphite (in which amounts of carbon as solid solutions contained in ferrite and in fine carbides are extremely small and thus not considered) and the graphite steel has a microstructure in which graphite grains are distributed in a ferrite matrix in which undegraded pearlite does not exist.

Graphitization rate (%) = (1-amount of C in undegraded pearlite/amount of C in steel) × 100

(Here, the graphitization rate is 100% in the case where there is no undegraded pearlite)

[0043] All of the descriptions given above with reference to the graphite steel may be applied to a method for manufacturing a graphite steel to be described below. Although duplicate descriptions may be omitted, the omitted descriptions may also be applied thereto in the same manner.

[Method for Manufacturing Graphite Steel]

[0044] A method for manufacturing a graphite steel according to another embodiment of the present disclosure includes: preparing a billet including, in percent by weight (wt%), 0.60 to 0.90% of carbon (C), 2.0 to 2.5% of silicon (Si), 0.7 to 1.3% of manganese (Mn), 0.2 to 0.5% of sulfur (S), 0.01 to 0.05% of aluminum (Al), 0.005 to 0.02% of titanium (Ti), 0.0030 to 0.0150% of nitrogen (N), 0.0001 to 0.05% of calcium (Ca), and the balance of iron (Fe) and inevitable impurities; hot rolling the billet to prepare a wire rod; and performing graphitizing heat treatment on the prepared wire rod.

Rolling Process

[0045] In addition, according to an embodiment of the present disclosure, the hot rolling may include hot rolling in a temperature range of 900 to 1150°C. Specifically, the hot rolling may be performed by hot rolling after conducting heat treatment in a temperature range of 900 to 1150°C for a certain period of time.

[0046] The rolling temperature of the wire rod may be controlled in the range of 900 to 1150°C because surface defects easily occur or a rolling load increases during hot rolling at a temperature lower than 900°C making a rolling process difficult, and austenite grain size (AGS) increases at a temperature higher than 1150°C so that graphitizing heat treatment time increases after hot rolling the wire rod.

Graphitizing Heat Treatment Process

[0047] In addition, according to an embodiment of the present disclosure, the graphitizing heat treatment may include heat treatment in a temperature range of 700 to 800°C for 5 hours or more, preferably, for 5 hours to 20 hours.

[0048] If the wire rod is heat-treated in a temperature range of 700 to 800°C for 5 hours or more, the graphitization rate may be 95% or more. However, at a temperature lower than 700°C, graphitizing heat treatment time increases to exceed 20 hours. At a temperature higher than 800°C, not only graphitizing heat treatment time increases, but also austenite is formed by reverse-transformation of pearlite and pearlite may be formed during cooling. Thus, they are not desirable.

[0049] Hereinafter, the present disclosure will be described in more detail with reference to the following examples.

[0050] These embodiments are provided to fully convey the scope of the disclosure to those skilled in the art. The present disclosure may, however, be embodied in many different forms and should not be construed as limited to the exemplary embodiments set forth herein.

[Examples]

[0051] Billets having compositions shown Table 1 below were maintained at a heating temperature of 1050°C for 90 minutes and rolled at a high speed to prepare wire rods having a diameter of 19 mm. In this regard, graphitizing heat treatment times and graphitization rates are shown in Table 2. In addition, graphitizing heat treatment was performed by constantly applying "Al temperature - 50°C" as a graphitizing heat treatment temperature.

[0052] In Tables 1 and 2 below, Examples 1 to 11 show graphite steel wire rods satisfying the composition range of alloying elements and manufacturing conditions of the present disclosure, and Comparative Examples 1 to 7 show wire rods not satisfying the composition range of alloying elements and/or manufacturing conditions of the present disclosure.

[Table 1]

Category	Composition of alloying elements (wt%)							
	C	Si	Mn	S	Al	Ti	N	Ca
Example 1	0.67	2.1	0.85	0.31	0.015	0.015	0.005	0.010
Example 2	0.85	2.15	0.96	0.24	0.023	0.017	0.008	0.020
Example 3	0.72	2.35	1.07	0.35	0.043	0.007	0.010	0.015
Example 4	0.68	2.18	1.16	0.45	0.035	0.009	0.009	0.030
Example 5	0.82	2.25	0.95	0.35	0.040	0.012	0.014	0.040
Example 6	0.62	2.48	0.80	0.25	0.042	0.006	0.012	0.045
Example 7	0.73	2.42	1.20	0.30	0.034	0.011	0.006	0.035
Example 8	0.78	2.32	1.25	0.43	0.019	0.016	0.008	0.030
Example 9	0.85	2.15	0.95	0.27	0.027	0.009	0.013	0.025
Example 10	0.75	2.26	1.15	0.26	0.030	0.018	0.007	0.015
Example 11	0.73	2.46	1.20	0.42	0.020	0.008	0.008	0.035
Comparative	0.63	2.00	<u>1.35</u>	<u>0.05</u>	<u>0.005</u>	0.016	0.001	<u>0.060</u>

(continued)

Example 1								
Comparative Example 2	0.68	2.20	<u>1.41</u>	<u>0.13</u>	<u>0.006</u>	0.020	0.002	<u>0.065</u>
Comparative Example 3	0.73	2.25	<u>1.50</u>	<u>0.56</u>	<u>0.075</u>	0.009	<u>0.018</u>	<u>0.080</u>
Comparative Example 4	<u>0.95</u>	2.15	<u>0.40</u>	<u>0.11</u>	<u>0.060</u>	0.018	<u>0.020</u>	<u>0.070</u>
Comparative Example 5	0.55	<u>2.60</u>	<u>0.56</u>	<u>0.60</u>	<u>0.003</u>	<u>0.025</u>	<u>0.025</u>	<u>0.100</u>
Comparative Example 6	0.80	<u>2.75</u>	<u>0.65</u>	<u>0.15</u>	<u>0.065</u>	<u>0.030</u>	<u>0.021</u>	<u>0.085</u>
Comparative Example 7	0.75	<u>2.80</u>	<u>0.60</u>	<u>0.10</u>	<u>0.060</u>	<u>0.002</u>	<u>0.022</u>	<u>0.070</u>

[Table 2]

Category	Graphitizing Heat Treatment		Machinability (%)
	Hour (hr)	Graphitization rate (%)	
Example 1	6.0	99	100
Example 2	9.5	99	100
Example 3	11.0	100	100
Example 4	6.5	100	100
Example 5	13.5	100	100
Example 6	5.5	99.5	100
Example 7	16.5	100	100
Example 8	8.2	98.5	100
Example 9	18.5	100	100
Example 10	5.7	98	100
Example 11	12.5	99	100
Comparative Example 1	<u>3.5</u>	<u>86</u>	<u>88</u>
Comparative Example 2	<u>2.0</u>	<u>85</u>	<u>80</u>
Comparative Example 3	<u>3.0</u>	<u>86</u>	<u>89</u>
Comparative Example 4	<u>4.5</u>	<u>84</u>	<u>92</u>
Comparative Example 5	<u>2.5</u>	<u>91</u>	<u>84</u>
Comparative Example 6	<u>3.0</u>	<u>92</u>	<u>93</u>
Comparative Example 7	<u>4.5</u>	<u>90</u>	<u>90</u>

[0053] In Table 2, a (100%-graphitization rate) structure consists of MnS inclusions, pearlite, and some common inclusions, and a graphitized structure consists of ferrite and graphite grains.

[0054] In Table 2, machinability is a value based on machinability of common free-cutting steels (100% refers to an equivalent level).

[0055] It may be confirmed that graphitization fraction and machinability may be achieved under the conditions for manufacturing graphite free-cutting steel as shown in Table 2.

[0056] Hereinafter, Examples and Comparative Examples will be evaluated with reference to Tables 1 and 2.

[0057] In Examples 1 to 11, it was confirmed that the graphitization rates were not less than 98.5% and machinability was 100% of that of lead free-cutting steels because the compositions of alloying elements and manufacturing conditions of the present disclosure were satisfied.

[0058] On the contrary, according to Comparative Examples 1 to 7 in which Ca contents exceed 0.05 wt% in the compositions of alloying elements and graphitizing heat treatment was maintained for less than 5 hours, it was confirmed

that the graphitization rates were not more than 92% and machinability was also not more than 95%.

[0059] Specifically, in the graphite steels according to Comparative Examples 1 and 2 including greater than 1.3 wt% of Mn, less than 0.2 wt% of S, and greater than 0.05 wt% of Ca, machinability was only 88% and 95% of that of lead free-cutting steels due to insufficient formation of MnS inclusions and the graphitization rates were not more than 86% because graphitizing heat treatment was maintained for 3.5 hours or less.

[0060] In addition, in the graphite steel of Comparative Example 3 including 1.50 wt% of Mn, 0.56 wt% of S, and 0.08 wt% of Ca, machinability was only 89% of that of lead free-cutting steel and the graphitization rate was only 86% because graphitizing heat treatment was maintained for 3.0 hours.

[0061] In addition, in the graphite steel of Comparative Example 4 including 0.95 wt% of C, 0.40 wt% of Mn, 0.011 wt% of S, and 0.07 wt% of Ca, machinability was only 92% of that of lead free-cutting steels and the graphitization rate was only 84% because graphitizing heat treatment was maintained for 4.5 hours.

[0062] In addition, in the graphite steel of Comparative Example 5 including 0.55 wt% of C, 2.6 wt% of Si, 0.56 wt% of Mn, 0.60 wt% of S, 0.025 wt% of Ti, and 0.1 wt% of Ca, machinability was only 91% of that of lead free-cutting steels and the graphitization rate was only 91% because graphitizing heat treatment was maintained for 2.5 hours.

[0063] In addition, in the graphite steel of Comparative Example 6 including 2.7 wt% of Si, 0.65 wt% of Mn, 0.15 wt% of S, 0.03 wt% of Ti, and 0.085 wt% of Ca, machinability was only 93% of that of lead free-cutting steels and the graphitization rate was only 92% because graphitizing heat treatment was maintained for 3.0 hours.

[0064] In addition, in the graphite steel of Comparative Example 7 including 2.8 wt% of Si, 0.60 wt% of Mn, 0.10 wt% of S, 0.002 wt% of Ti, and 0.07 wt% of Ca, machinability was only 90% of that of lead free-cutting steels and the graphitization rate was only 90% because graphitizing heat treatment was maintained for 4.5 hours.

[0065] While the present disclosure has been particularly described with reference to exemplary embodiments, it should be understood by those of skilled in the art that various changes in form and details may be made without departing from the spirit and scope of the present disclosure.

[Industrial Applicability]

[0066] According to the present disclosure, the graphite free-cutting steel according to the present disclosure having excellent machinability may replace conventional free-cutting steels and may be eco-friendly by replacing harmful substances such as Pb and Bi, and therefore the present disclosure has industrial applicability.

Claims

1. A graphite steel comprising, in percent by weight (wt%), 0.60 to 0.90% of carbon (C), 2.0 to 2.5% of silicon (Si), 0.7 to 1.3% of manganese (Mn), 0.2 to 0.5% of sulfur (S), 0.01 to 0.05% of aluminum (Al), 0.005 to 0.020% of titanium (Ti), 0.003 to 0.015% of nitrogen (N), 0.0001 to 0.050% of calcium (Ca), and the balance of iron (Fe) and inevitable impurities, wherein the graphite steel includes a microstructure in which graphite grains are distributed in a ferrite matrix, has a graphitization rate of 95% or more, and includes a total of 5 wt% of MnS inclusions and pearlite.
2. The graphite steel according to claim 1, wherein the graphite steel has a graphitization rate of 99% or more.
3. The graphite steel according to claim 1, wherein the graphite steel does not include at least one phosphorus (P) and oxygen (O).
4. A method for manufacturing a graphite steel, the method comprising:
 - preparing a billet including, in percent by weight (wt%), 0.60 to 0.90% of carbon (C), 2.0 to 2.5% of silicon (Si), 0.7 to 1.3% of manganese (Mn), 0.2 to 0.5% of sulfur (S), 0.01 to 0.05% of aluminum (Al), 0.005 to 0.020% of titanium (Ti), 0.003 to 0.015% of nitrogen (N), 0.0001 to 0.05% of calcium (Ca), and the balance of iron (Fe) and inevitable impurities;
 - hot rolling the billet to prepare a wire rod; and
 - performing graphitizing heat treatment on the prepared wire rod.
5. The method according to claim 4, wherein the hot rolling comprises hot rolling in a temperature range of 900°C to 1150°C.
6. The method according to claim 4, wherein the graphitizing heat treatment comprises heat treatment in a temperature

range of 700°C to 800°C for 5 hours or more.

7. The method according to claim 6, wherein the graphitizing heat treatment is performed for 5 hours to 20 hours.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2022/020233

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/02(2006.01)i; C22C 38/04(2006.01)i; C22C 38/06(2006.01)i; C22C 38/14(2006.01)i; C22C 38/00(2006.01)i;
C22C 38/60(2006.01)i; C21D 5/14(2006.01)i; B21B 1/16(2006.01)i; C21D 9/52(2006.01)i; C21D 8/02(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/02(2006.01); B21B 1/16(2006.01); C21D 6/00(2006.01); C21D 6/02(2006.01); C22C 38/00(2006.01);
C22C 38/04(2006.01); C22C 38/06(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: 흑연강(graphite steel), 열간 압연(hot rolling), 선재(wire rod), 흑연화 열처리
(graphitization heat treatment), 탄소(C), 실리콘(Si), 망간(Mn), 황(S), 알루미늄(Al), 티타늄(Ti), 질소(N), 칼슘(Ca)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2003-034840 A (NIPPON STEEL CORP.) 07 February 2003 (2003-02-07) See paragraph [0026]; and claims 1-2 and 4.	1-7
Y	KR 10-1674826 B1 (POSCO) 10 November 2016 (2016-11-10) See paragraphs [0003] and [0060]-[0061]; and claim 5.	1-7
A	KR 10-2020-0075643 A (POSCO) 26 June 2020 (2020-06-26) See claims 5-9.	1-7
A	KR 10-2019-0075512 A (POSCO) 01 July 2019 (2019-07-01) See paragraph [0016].	1-7
A	JP 07-188847 A (KAWASAKI STEEL CORP.) 25 July 1995 (1995-07-25) See paragraph [0045].	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

“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

16 March 2023

Date of mailing of the international search report

17 March 2023

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2022/020233

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2003-034840 A	07 February 2003	JP 4494676 B2	30 June 2010
KR 10-1674826 B1	10 November 2016	None	
KR 10-2020-0075643 A	26 June 2020	KR 10-2224044 B1	09 March 2021
KR 10-2019-0075512 A	01 July 2019	CN 109943772 A	28 June 2019
		CN 109943772 B	12 March 2021
		JP 2019-112711 A	11 July 2019
		JP 6860532 B2	14 April 2021
		KR 10-2042063 B1	08 November 2019
JP 07-188847 A	25 July 1995	None	

Form PCT/ISA/210 (patent family annex) (July 2022)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- KR 1020150057400 [0007]