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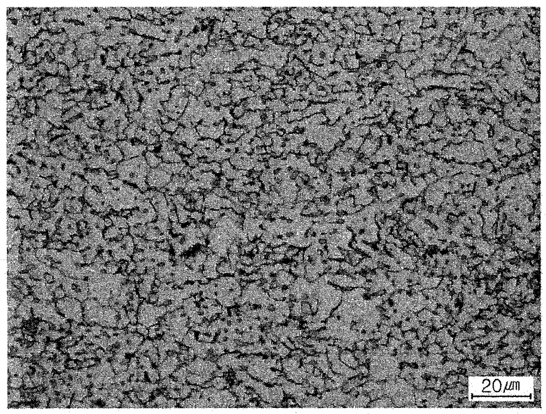
(54) LOW-YIELD RATIO STEEL SHEET HAVING EXCELLENT LOW-TEMPERATURE TOUGHNESS AND METHOD FOR MANUFACTURING SAME

(57) An aspect of the present invention relates to a low-yield ratio steel sheet having excellent low-temperature toughness, the steel sheet comprising, in terms of weight%, 0.05-0.1% of C, 0.3-0.7% of Si, 1.0-2.0% of Mn, 0.005-0.04% of Al, 0.04-0.07% of Nb, 0.001-0.02% of Ti, 0.05-0.4% of Cu, 0.1-0.6% of Ni, 0.01-0.08% of Mo, 0.001-0.008% of N, 0.015% or less of P, 0.003% or less of S, and the remainder Fe and unavoidable impurities, wherein a microstructure comprises, by area fraction, -80-92% of ferrite and 8-20% of MA (martensite/austenite mixed structure), the average size of the MA measured for a circle-equivalent diameter being 3# or less.

【Fig. 2】



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Description

[Technical Field]

[0001] The present disclosure relates to a low-yield ratio steel sheet having excellent low-temperature toughness and a method for manufacturing the same.

[Background Art]

[0002] In addition to steel materials for shipbuilding and maritime structures, the development of steel materials having a relatively low-yield ratio, in addition to having relatively low-temperature toughness, is required for applications in industrial fields requiring formability and seismic resistance.

[0003] Since steel materials having a relatively low-yield ratio have a great difference between yield strength and tensile strength, such steel materials have relatively high formability, and the start of plastic deformation of the steel materials may be delayed until fracture occurs, such that collapses caused by external force may be prevented, owing to absorption of energy during the delay. In addition, even when a structure is deformed, the structure may be repaired before collapse to prevent damage to property and human life caused by breakage of the structure.

[0004] Techniques for manufacturing steel materials having a two-phase structure have been developed to guarantee a relatively low-yield ratio. Specifically, a relatively low-yield ratio has been realized by forming soft ferrite as a first phase, and martensite, pearlite, or bainite as a second phase.

[0005] However, the second phase, which is relatively hard, may decrease impact toughness, and since the content of carbon increases to form the second phase, toughness of a weld zone may deteriorate. Therefore, there may be problems that brittle fraction may occur in a structure at a relatively low temperature.

[0006] Therefore, a technique for guaranteeing a relatively low-yield ratio and relatively low temperature toughness has been disclosed in Patent Document 1.

[0007] In Patent Document 1, a relatively low-yield ratio and relatively high low-temperature toughness are guaranteed by a microstructure configured to include MA (a mixed structure of martensite/austenite) in an amount of 2 vol% to 10 vol% and acicular ferrite in an amount of 90 vol% or greater.

[0008] In Patent Document 1, a yield ratio of about 0.8 may be guaranteed, but may not be sufficient to ensure seismic resistance, due to not guaranteeing a relatively low-yield ratio. Therefore, in order to secure a lower yield ratio, there is a need for the development of a relatively high strength steel sheet having relatively low-yield ratio and relatively low temperature toughness, and a method for manufacturing the same.

(Prior Art Documents)

[0009] (Patent Document 1) Korean Patent Publication No. 2013-0076577

[Disclosure]

[Technical Problem]

[0010] An aspect of the present disclosure is to provide a low-yield ratio steel sheet having excellent low-temperature toughness and a method for manufacturing the same.

[0011] Aspects of the present disclosure are not limited to the above-mentioned aspects. The above-mentioned aspects and other aspects of the present disclosure will be clearly understood by those skilled in the art through the following description.

[Technical Solution]

[0012] According to an aspect of the present disclosure, a low-yield ratio steel sheet having excellent low-temperature toughness includes : by weight, 0.05% to 0.1% of carbon (C), 0.3% to 0.7% of silicon (Si), 1.0% to 2.0% of manganese (Mn), 0.005% to 0.04% of aluminum (Al), 0.04% to 0.07% of niobium (Nb), 0.001% to 0.02% of titanium (Ti), 0.05% to 0.4% of copper (Cu), 0.1% to 0.6% of nickel (Ni), 0.01% to 0.08% of molybdenum (Mo), 0.001% to 0.008% of nitrogen (N), 0.015% or less of phosphorus (P), 0.003% or less of sulfur (S), a remainder of iron (Fe), and inevitable impurities, wherein a microstructure of the low-yield ratio steel sheet comprises, by an area fraction, ferrite in an amount of 80 to 92% and MA (a mixed structure of martensite/austenite) in an amount of 8 to 20%, wherein the MA has an average size of 3 μm or less, when measured in equivalent circular diameter.

[0013] According to an aspect of the present disclosure, a method for manufacturing a low-yield ratio steel sheet having excellent low-temperature toughness, includes:

heating a slab to a temperature of 1050°C to 1200°C, the slab comprising, by weight, 0.05% to 0.1% of carbon (C), 0.3% to 0.7% of silicon (Si), 1.0% to 2.0% of manganese (Mn), 0.005% to 0.04% of aluminum (Al), 0.04% to 0.07% of niobium (Nb), 0.001% to 0.02% of titanium (Ti), 0.05% to 0.4% of copper (Cu), 0.1% to 0.6% of nickel (Ni), 0.01% to 0.08% of molybdenum (Mo), 0.001% to 0.008% of nitrogen (N), 0.015% or less of phosphorus (P), 0.003% or less of sulfur (S), a remainder of iron (Fe), and inevitable impurities;
hot rolling the heated slab in such a manner that a finish rolling termination temperature ranges from 760°C to 850°C, to obtain a hot-rolled steel sheet;
cooling the hot-rolled steel sheet to a temperature of 450°C or less at a cooling rate of 5°C/s or greater; and
after heating the cooled hot-rolled steel sheet to a temperature of 850°C to 960°C, performing a normalizing heat treatment, maintaining the hot-rolled steel sheet for [1.3t+(10~30)] minutes, where t refers to a thickness of the hot-rolled steel sheet in millimeters (mm).

[0014] In addition, the above-described aspects of the present disclosure do not include all aspects or features of the present disclosure. Other aspects or features, and effects of the present disclosure will be clearly understood from the following descriptions of exemplary embodiments.

[Advantageous Effects]

[0015] According to an aspect of the present disclosure, a relatively low-yield ratio and an excellent low-temperature toughness may be secured, and in particular, a low-yield ratio within the range of 0.65 or less, relatively high formability, and relatively high seismic resistance may be guaranteed. Therefore, it may be applied not only to industrial fields such as construction, construction, and civil engineering which require seismic resistance, and but also to steel materials for shipbuilding and marine structures.

[Description of Drawings]

[0016]

FIG. 1 is a photograph of a microstructure before a normalizing heat treatment of Test No. 1, an inventive example.
FIG. 2 is a photograph of a microstructure after a normalizing heat treatment of Test No. 1, an inventive example.
FIG. 3 is a photograph of a microstructure after a normalizing heat treatment of Test No. 9, a comparative example.
FIG. 4 is a photograph of a microstructure after a normalizing heat treatment of Test No. 10, a comparative example.

[Best Mode for Invention]

[0017] Hereinafter, embodiments of the present disclosure will be described in detail. The disclosure may, however, be exemplified in many different forms and should not be construed as being limited to the specific embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the present disclosure to those skilled in the art.

[0018] The inventors of the present disclosure have recognized that although formability is somewhat ensured by a yield ratio of about 0.8 in the prior art, the yield ratio level obtainable in the related art is not sufficiently low to guarantee seismic resistance. Therefore, the inventors have conducted deep research to address this problem.

[0019] As a result, the inventors have found the followings: in order to realize a relatively low-yield ratio, relatively high hardness difference between a base material and a second phase increases, and a relatively uniform distribution of MA (a mixed structure of martensite/austenite) are advantageous; and in the case of Patent Document 1, the hardness difference between a base material, as acicular ferrite, and MA is insufficient, and the MA is formed along grain boundaries and is coarse, thereby failing to obtain a sufficiently low-yield ratio.

[0020] The inventors have found that a yield ratio of 0.65 or less can be obtained by forming ferrite as a microstructure of a base material and uniformly distributing a relatively fine phase of MA along ferrite grain boundaries and in ferrite grains, and this structure can be obtained by adjusting a structure to have bainite before performing a normalizing heat treatment; and, then, based on the above, the inventors have completed the present disclosure.

Low-Yield Ratio Steel Sheet having Excellent Low-Temperature Toughness

[0021] Hereinafter, a low-yield ratio steel sheet having excellent low-temperature toughness will be described in detail according to an embodiment of the present disclosure.

[0022] According to an embodiment of the present disclosure, a low-yield ratio steel sheet having excellent low-temperature toughness includes : by weight, 0.05% to 0.1% of carbon (C), 0.3% to 0.7% of silicon (Si), 1.0% to 2.0% of manganese (Mn), 0.005% to 0.04% of aluminum (Al), 0.04% to 0.07% of niobium (Nb), 0.001% to 0.02% of titanium (Ti), 0.05% to 0.4% of copper (Cu), 0.1% to 0.6% of nickel (Ni), 0.01% to 0.08% of molybdenum (Mo), 0.001% to 0.008% of nitrogen (N), 0.015% or less of phosphorus (P), 0.003% or less of sulfur (S), a remainder of iron (Fe), and inevitable impurities,

wherein a microstructure of the low-yield ratio steel sheet comprises, by an area fraction, ferrite in an amount of 80 to 92% and MA (a mixed structure of martensite/austenite) in an amount of 8 to 20%, wherein the MA has an average size of 3 μm or less, when measured in equivalent circular diameter.

[0023] First, the alloy composition of the present disclosure will be described in detail. Hereinafter, the content of each element is given in wt%, unless otherwise specified.

Carbon (C): 0.05% to 0.1%

[0024] In the present disclosure, C may be an element leading to solid solution strengthening and being present as a carbonitride of Nb or the like. Therefore, C may guarantee tensile strength.

[0025] When the content of C is less than 0.05%, the above-mentioned effects are insufficient. When the content of C is greater than 0.1%, MA is coarsened, and pearlite is formed, thereby deteriorating impact characteristics at low temperature and making it difficult to sufficiently form bainite. Therefore, the C content is preferably 0.05% to 0.1%.

[0026] Further, a more preferable lower limit of the C content may be 0.055%, and a still more preferable lower limit thereof may be 0.06%. Further, a more preferable upper limit of the C content may be 0.095%, and a still more preferable upper limit thereof may be 0.09%.

Silicon (Si): 0.3% to 0.7%

[0027] Si may be added to assist Al in deoxidizing molten steel and guaranteeing yield strength and tensile strength. Si may be also an element for controlling the desired MA fraction in the present disclosure.

[0028] When the content of Si is less than 0.3%, the above-mentioned effects are insufficient. When the content of Si is greater than 0.7%, due to coarsening of MA, impact properties may deteriorate, and welding characteristics may deteriorate. Therefore, the content of Si is preferably 0.3% to 0.7%.

[0029] Further, a more preferable lower limit of the Si content may be 0.35%, and a still more preferable lower limit thereof may be 0.4%. Further, a more preferable upper limit of the Si content may be 0.65%, and a still more preferable upper limit thereof may be 0.6%.

Manganese (Mn): 1.0% to 2.0%

[0030] Mn may be an element that contributes greatly to the strength enhancement effect by solid solution strengthening and helps the formation of bainite.

[0031] When the content of Mn is less than 1.0%, the above-mentioned effects are insufficient. When excessively added, Mn may cause inclusion of MnS and degradation of toughness due to central segregation. Therefore, an upper limit of the content of Mn may be set to be 2.0%. Therefore, the Mn content is preferably 1.0% to 2.0%.

[0032] Further, a more preferable lower limit of the Mn content may be 1.1%, and a still more preferable lower limit thereof may be 1.2%. Further, a more preferable upper limit of the Si content may be 1.95%, and a still more preferable upper limit thereof may be 1.9%.

Aluminum (Al) : 0.005% to 0.04%

[0033] Al may be a major deoxidizer of steel and may be added in an amount of 0.005% or greater. When the content of Al is greater than 0.04%, this effect may be saturated, and the fraction and size of Al_2O_3 inclusions may increase to cause a decrease in low temperature toughness.

Niobium (Nb) : 0.04% to 0.07%

[0034] Nb may be an element staying in a solid solution state or precipitating carbonitrides during rolling or cooling, thereby suppressing recrystallization, promoting formation of a fine structure, and increasing strength. When the content of Nb is less than 0.04%, the above-mentioned effects may be insufficient. When the content of Nb exceeds 0.04%, the toughness of a base material and the toughness of the steel sheet after welding may be lowered.

Titanium (Ti): 0.001% to 0.02%

[0035] Ti may form precipitates by combining with oxygen or nitrogen, thereby suppressing coarsening of a structure, contributing to refinement, and improving toughness.
[0036] When the content of Ti is less than 0.001%, the above-mentioned effects may be insufficient. When the content of Ti exceeds 0.02%, coarse precipitates may be formed to cause fracture.

Copper (Cu): 0.05% to 0.4%

[0037] Cu may be an element that does not markedly deteriorate impact characteristics and improves strength by solid solution strengthening and precipitation strengthening. For sufficient strength improvements, Cu is required to be added in an amount of 0.05% or greater. When the content of Cu exceeds 0.4%, surface cracks may be formed in the steel sheet due to Cu thermal shock.

Nickel (Ni): 0.1% to 0.6%

[0038] Although significant strength improvements are not obtained by increasing the content of Ni, Ni may improve strength and toughness at the same time, and may promote the formation of bainite by lowering the Ar3 temperature.
[0039] When the content of Ni is less than 0.1%, the above-mentioned effects may be insufficient. When the content of Ni exceeds 0.6%, manufacturing costs may increase and weldability may deteriorate.

Molybdenum (Mo): 0.01% to 0.08%

[0040] Mo, acting as an austenite stabilizing element, may have an effect on increasing the amount of MA, and may play a large role in improving strength. In addition, Mo may prevent a decrease in strength during a heat treatment process, and may promote the formation of bainite.
[0041] Since Mo may be an expensive alloying element, there may be a problem that the production cost increases when added in relatively large amounts. Therefore, in the present disclosure, MA may be secured by adding a relatively large amount of Si, Nb, and the like. In the alloy composition of the present disclosure, when Mo is added by 0.01% or more, the above-mentioned effect may be sufficiently secured. When the content of Mo exceeds 0.3%, manufacturing costs may increase, and the toughness of a base material and the toughness of the supply pipe after welding may decrease.

Nitrogen (N): 0.001% to 0.008%

[0042] N may be an element useful in improving strength and toughness, because N forms precipitates together with elements such as Ti, Nb, Al, or the like, and may thus lead to the formation of fine austenite when a slab is heated.
[0043] When the content of N is less than 0.001%, the above-mentioned effects may be insufficient. When the content of N is greater than 0.008%, surface cracks may be formed at a high temperature, and N remaining in an atomic state after precipitation may reduce toughness.

Phosphorus (P): 0.015% or less

[0044] P, as an impurity, may cause grain boundary segregation, and may thus cause embrittlement of steel. Therefore, it is important to control the upper limit of the content thereof. Preferably, the upper limit of the content of P may be controlled to be 0.015% or less.
[0045] The lower limit of the P content is not particularly limited, but 0% may be excluded.

Sulfur (S): 0.003% or less

[0046] S may be an impurity mainly combining with Mn to form MnS inclusions which are factors decreasing low temperature toughness. Therefore, it is important to control the upper limit of the content of S. Preferably, the upper limit of the content of S may be controlled to be 0.003% or less.
[0047] The lower limit of the S content is not particularly limited, but 0% may be excluded.
[0048] The other component of the steel sheet of the present disclosure is iron (Fe). Impurities of raw materials or manufacturing environments may be inevitably included in the steel sheet, and such impurities may not be removed from the steel sheet. 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.

[0049] Hereinafter, a microstructure of a low-yield ratio steel sheet having excellent low-temperature toughness, according to one aspect of the present disclosure, will be described in detail.

[0050] According to one aspect of the present disclosure, the microstructure of the low-yield ratio steel sheet having excellent low-temperature toughness may include, by an area, ferrite in an amount of 80 to 92% and MA (a mixed structure of martensite/austenite) in an amount of 8 to 20%, wherein the MA has an average size of 3 μm or less, when measured in equivalent circular diameter. Hereinafter, a fraction of the microstructure refers to an area fraction, unless otherwise specified.

[0051] The ferrite may guarantee basic toughness and strength, and it is preferable that a fraction of ferrite be 80% or greater. In addition, it is preferable that an upper limit of a fraction of ferrite be 92% for guaranteeing the formation of sufficient MA. Furthermore, the ferrite of the steel sheet may not include acicular ferrite. Since the difference in hardness between acicular ferrite and MA is relatively small, acicular ferrite does not guarantee a sufficient low-yield ratio.

[0052] When the fraction of MA is less than 8%, it may be difficult to obtain a low-yield ratio with the range of 0.65 or less, and when the fraction of MA is greater than 20%, impact toughness may decrease, and elongation may decrease. In addition, when the average size of MA measured in equivalent circular equivalent is greater than 3 μm, MA may mainly be formed along grain boundaries, thereby making it difficult to guarantee a uniform distribution of MA and a relatively low-yield ratio.

[0053] Inevitable phases other than the ferrite and MA may be included in the steel sheet, and these phases may not be excluded. For example, pearlite may be included in the steel sheet in an area% of 1 or less.

[0054] In this case, in order to guarantee relatively low-yield ratio characteristics and relatively low temperature toughness, in addition to adjusting the fraction and size of MA as described above, it is preferable that when a 100 μm-long straight line is drawn on the steel sheet of the present disclosure, MA be present on five (5) to thirteen (13) sites on the straight line. For example, when several straight line are vertically or horizontally drawn on a microstructure photograph having a size of 100 μm × 100 μm, MA may be present at five (5) to thirteen (13) sites on each straight line on average. MA formed along grain boundaries mainly leads to fracture initiation, and when the above-described condition is satisfied, a relatively low-yield ratio may be obtained because the distribution of MA is uniform along grain boundaries and in grains.

[0055] In addition, a ratio of MA existing in ferrite grains to MA existing along ferrite grain boundaries may be 1 : 3 to 1 : 10. The ratio refers to a ratio of the numbers of MA sites, and when the ratio is within the above-mentioned range, MA may uniformly exist in ferrite grains in an amount of 0.5 area% to 5 area%.

[0056] In addition, the ferrite of the steel sheet may have an average size measured in equivalent circular diameter within the range of 20 μm or less. When the average size of ferrite exceeds 20 μm, it may be difficult to ensure sufficient toughness and strength.

[0057] Meanwhile, the steel sheet according to an embodiment of the present disclosure is a steel sheet treated by a normalizing heat treatment, and the microstructure of the steel sheet before the normalizing heat treatment may have bainite in an amount of 50 area% to 90 area%. Since the microstructure of the steel sheet before the heat treatment has bainite in which carbides are contained, MA may be uniformly distributed along grain boundaries and in grains after the heat treatment. Therefore, it is preferable that the microstructure of the steel sheet before the heat treatment have bainite in an amount of 50 area% to 90 area%.

[0058] In addition, the steel sheet according to an embodiment of the present disclosure may have a yield ratio within the range of 0.5 to 0.65 and a low temperature impact toughness within the range of 100 J or greater at -40°C. Since the steel sheet has a yield ratio within the range of 0.65 or less, for example, has a great difference between yield strength and tensile strength, the steel sheet may have high formability, and the initiation of plastic deformation of the steel sheet may be delayed until fracture may occur such that collapse caused by external force may be prevented owing to absorption of energy during the delay. Therefore, the steel sheet may be applied not only to shipbuilding and marine structures but also to industrial fields requiring formability and seismic resistance.

[0059] In this case, the steel sheet may have a yield strength within the range of 350 MPa to 400 MPa and a tensile strength within the range of 600 MPa or greater.

Method for manufacturing Low-Yield Ratio Steel Sheet having excellent Low-Temperature Toughness

[0060] Hereinafter, a method for manufacturing a low-yield ratio steel sheet having excellent low-temperature toughness will be described in detail according to another embodiment of the present disclosure.

[0061] According to another embodiment of the present disclosure, a method for manufacturing a low-yield ratio steel sheet having excellent low-temperature toughness, includes:

heating a slab having the above-described alloy composition to 1050°C to 1200°C;
hot rolling the heated slab in such a manner that a finish rolling termination temperature ranges from 760°C to 850°C, to obtain a hot-rolled steel sheet;
cooling the hot-rolled steel sheet to a temperature of 450°C or less at a cooling rate of 5°C/s or greater; and

after heating the cooled hot-rolled steel sheet to a temperature of 850°C to 960°C, performing a normalizing heat treatment maintaining the hot-rolled steel sheet for [1.3t+(10~30)] minutes, where t refers to a thickness of the hot-rolled steel sheet in millimeters (mm).

Heating Slab

[0062] A slab having the above-described alloy composition may be heated to a temperature of 1050°C to 1200°C.
[0063] When the heating temperature is higher than 1200°C, austenite grains may be coarsened to cause a decrease in toughness, and if the heating temperature is lower than 1050°C, elements such as Ti and Nb may not be sufficiently dissolved to cause a decrease in strength.

Hot Rolling

[0064] The heated slab may be hot rolled such that a finish rolling termination temperature may range from 760°C to 850°C, to obtain a hot-rolled steel sheet. In general, a normal rolling process may be performed on heat-treated steel materials at a rolling temperature of 850°C to 1000°C. In the present disclosure, bainite may be formed as an initial microstructure. Therefore, instead of a general rolling process resulting in a ferrite-pearlite microstructure, a controlled rolling process is required to finish rolling at a relatively low temperature.
[0065] Recrystallization rolling is required during the hot rolling process to obtain fine austenite grains, and as the reduction ratio per pass increases, physical properties may be improved. It is required to finish unrecrystallized region rolling at a temperature equal to or greater than the Ar3 temperature of the steel material, for example, at a temperature of about 760°C or greater. More specifically, the finish rolling termination temperature may be set to be 760°C to 850°C. When the finish rolling termination temperature exceeds 850°C, it is difficult to suppress ferrite-pearlite transformation. When the finish rolling termination temperature is lower than 760°C, a non-uniform microstructure may be formed in a thickness direction, and an intended microstructure may not be formed because of a decrease in rolling force by rolling roll loads. The finish rolling may be terminated at a temperature of 760°C to 850°C to suppress ferrite-pearlite transformation and form bainite by cooling. Bainite formed as an initial microstructure is to obtain uniform distribution of MA after a heat treatment. In a ferrite-pearlite microstructure, MA may mainly be formed along grain boundaries, while in a bainite microstructure, MA may be formed along grain boundaries and in grains as well.

Cooling

[0066] The hot-rolled steel sheet may be cooled to a temperature of 450°C or less at a cooling rate of 5°C/s or greater.
[0067] Accelerated cooling after hot rolling is required to form an intended microstructure in inventive steel. Bainite is required to obtain fine and uniform MA, and the termination temperature and rate of the cooling are adjusted to form bainite. When the cooling termination temperature is higher than 450°C, coarse grains may be formed, and coarse MA may be formed after a heat treatment because of coarse carbides, causing a decrease in toughness and making it difficult to form bainite in an amount of 50 area% or greater.
[0068] When the cooling rate is less than 5°C/s, acicular ferrite or a ferrite+pearlite microstructure may be formed in large amounts to result in a decrease in strength, the formation of a coarse ferrite+pearlite microstructure instead of the formation of a two-phase microstructure of ferrite+MA or a sharp decrease in the amount of a second phase may be resulted after a heat treatment, and it is difficult to form bainite in an amount of 50 area% or greater.
[0069] At this time, the microstructure of the cooled hot-rolled steel sheet may be 50 area% to 90 area% by of bainite. Since the microstructure of the steel sheet before the heat treatment may be made of bainite in which the carbide is present, it may be possible to evenly distribute the MA in the grains and the grain boundaries after the heat treatment, such that the microstructure of the steel sheet before heat treatment is preferably in a range of 50 area% to 90 area%.

Normalizing Heat Treatment

[0070] The cooled hot-rolled steel sheet may be heated to a temperature of 850°C to 960°C, and may be then maintained for [1. 3t+ (10~30)] minutes . In this case, t refers to the thickness of the steel sheet measured in millimeters (mm).
[0071] When the normalizing temperature is less than 850°C or the maintaining period of time is less than (1.3t+10) minutes, cementite and MA may not easily dissolve in pearlite and bainite, and thus the amount of dissolved carbon (C) may decrease. Therefore, it may be difficult to guarantee strength, and a finally remaining hardened phase may be coarse.
[0072] When the normalizing temperature exceeds 960°C or the maintaining period of time is greater than (1.3t+30) minutes, all the carbides existing in bainite grains may move to grain boundaries or coarsening of carbide may occur. Therefore, final MA may not have an intended size and may not be uniformly distributed. In addition, grain growth may occur to result in a decrease in strength and deterioration of impact characteristics.

[Mode for Invention]

[0073] Hereinafter, the present disclosure will be described more specifically through examples. However, the following examples should be considered in a descriptive sense only and not for purposes of limitation. The scope of the present invention is defined by the appended claims, and modifications and variations may be reasonably made therefrom.

[0074] Slabs were prepared by performing a continuous casting process on molten steel having the compositions shown in Table 1 below. Steel sheets were manufactured by performing rolling, cooling, and normalizing heat treatment processes on the slabs under the manufacturing conditions shown in Table 2 below.

[0075] Table 3 shows the bainite fraction and mechanical properties of each of the steel sheets measured before the normalizing heat treatment process.

[0076] After the normalizing heat treatment process, the MA fraction, the average MA size, the number of MA sites on a 100 μm long line, and the mechanical properties of each of the steel sheets were measured as shown in Table 4. In inventive examples, ferrite was formed in addition to MA, and the average grain size of the ferrite was 20 μm or less, which was not recorded.

[0077] The average MA size refers to an equivalent circular diameter, and the number of MA sites on a 100 μm lone line was measured by vertically or horizontal drawing ten (10) straight lines on a microstructure photograph having a size of 100 μm × 100 μm, counting the number of MA sites on each of the straight lines, and averaging the numbers.

[Table 1]

	Steel	C	Si	Mn	P	S	Al	Ni	Mo	Ti	Nb	Cu	N
[1]IS	A	0.081	0.495	1.61	0.01	0.002	0.031	0.15	0.069	0.012	0.047	0.245	0.0037
IS	B	0.078	0.521	1.78	0.01	0.0018	0.026	0.26	0.054	0.013	0.051	0.239	0.0041
IS	C	0.084	0.453	1.75	0.009	0.0019	0.027	0.32	0.048	0.011	0.055	0.256	0.0038
IS	D	0.086	0.535	1. 64	0.007	0.0018	0.030	0.25	0.034	0.013	0.049	0.261	0.0034
[2]CS	E	0.046	0.503	1.69	0.009	0.002	0.011	0.147	0.068	0.013	0.042	0.26	0.0039
CS	F	0.085	0.11	1.65	0.012	0.002	0.029	0.15	0.068	0.012	0.045	0.246	0.0042
CS	G	0.084	0.495	1.67	0.009	0.002	0.032	0.147	0.059	0.01	0.021	0.264	0.0036
[1]IS: Inventive Steel, [2]CS: Comparative Steel													

[0078] In Table 1, the content of each element is given in wt%. Inventive steels A to D were used to prepare steel sheets satisfying the component ranges proposed in the present disclosure, and comparative steels E to G were used to prepare steel sheets not satisfying the component ranges proposed in the present disclosure. Comparative steel E lacked a C content, comparative steel F lacked a Si content, comparative steel G lacked a Mn content.

[Table 2]

	Test No.	Steel	Reheating Temp. (°C)	Finish Rolling Start Temp. (°C)	Finish Rolling Termination Temp. (°C)	Cooling Terminatio n Temp. (°C)	Cooling Rate (°C/s))	Normalizi ng Temp. (°C)	Normalizi ng Time (min)
[1]IE	1	A	1147	798	781	345	10.2	910	121
IE	2	B	1151	805	798	332	10.3	910	122
IE	3	C	1142	801	797	362	10.5	910	120
IE	**4**	D	1138	788	775	328	10.9	910	122
[2]CE	5	A	1150	965	<u>938</u>	367	12.3	910	121
CE	6	B	1134	794	779	<u>-</u>	<u>-</u>	910	120
CE	7	C	1148	803	785	385	10.2	910	<u>395</u>
CE	8	D	1129	791	780	<u>701</u>	8.3	910	121
CE	9	E	1136	809	802	365	10.3	910	119
CE	10	F	1152	810	799	335	10.1	910	124
CE	11	G	1148	803	786	387	11.6	910	119

[1]IE: Inventive Example, [2]CE: Comparative Example

[Table 3]

	Test No.	Steel	Before Normalizing Heat Treatment				
			Bainite (Area%)	Yield Strength (MPa)	Tensile Strength (MPa)	Yield Ratio	Elongation (%)
[1]IE	1	A	66	538	617	0.87	25.4
IE	2	B	71	524	642	0.82	22.5
IE	3	C	64	498	624	0.80	23.4
IE	4	D	80	503	621	0.81	21.5
[2]CE	5	A	8	492	587	0.84	22.5
CE	6	B	0	452	561	0.81	24.2
CE	7	C	64	507	644	0.79	25.1
CE	8	D	7	561	657	0.85	22.4
CE	9	E	1	497	580	0.86	24.3
CE	10	F	31	487	576	0.85	25.7
CE	11	G	27	477	553	0.86	21.7
[1]IE: Inventive Example, [2]CE: Comparative Example							

[Table 4]

	Test No.	Steel	After Normalizing Heat Treatment							
			MA Fractio n (Area%)	Average MA Size (μm)	Number of MA on 100 μm-long Line	Yield Strength (MPa)	Tensile Strength (MPa)	Yield Ratio	Elonga tion (%)	Impact Toughness (-40°C, J)
[1]IE	1	A	11.8	2.4	9	384	653	0.59	31.2	123
IE	2	B	12.7	2.3	9	375	642	0.58	32.1	154
IE	3	C	14.2	2.6	9	381	643	0.59	29.8	114
IE	4	D	16.5	2.1	8	362	639	0.57	30.8	109
[2]CE	5	A	3.4	6.1	2	371	468	0.79	25.6	58
CE	6	B	2.8	5.6	1	352	448	0.79	25.4	67
CE	7	C	3.5	4.5	1	341	474	0.72	24.9	52
CE	8	D	1.8	3.8	1	365	495	0.74	26.8	34
CE	9	E	0.4	5.0	0	342	438	0.78	26.7	132
CE	10	F	0.8	3.1	2	351	458	0.77	25.8	152
CE	11	G	1.2	5.3	2	348	445	0.78	24.1	117
[1]IE: Inventive Example, [2]CE: Comparative Example										

[0079] The inventive examples satisfying all of the alloy composition and the manufacturing conditions proposed in the present disclosure have a yield ratio of 0.65 or less and an impact toughness of 100 J or greater at -40°C.

[0080] Test Nos. 5, 6, 7, and 8 (comparative examples) satisfied the alloy composition proposed in the present disclosure, but did not satisfy the manufacturing conditions proposed in the present disclosure. Therefore, test Nos. 5, 6, 7, and 8 failed to guarantee a sufficiently low-yield ratio and had poor impact toughness at -40°C within the range of less than 100 J.

[0081] Test Nos. 9 to 11 (comparative examples) satisfied the manufacturing conditions proposed in the present disclosure, but did not satisfy the alloy composition proposed in the present disclosure. Therefore, test Nos. 9 to 11 failed to guarantee a sufficiently low-yield ratio, and was poor impact toughness at -40°C within the range of less than 100 J. In addition, it can be seen that the strength may also be deteriorated due to insufficient content of C, Si, and Nb.

[0082] As shown in Table 4, the MA fractions in the inventive examples are greater than those in the comparative examples. The reason for this is that: since the fraction of bainite was relatively high before the normalizing heat treatment process as seen from Table 3 above, carbides existing in grains and along grain boundaries of the initial bainite were transformed into fine MA. Also, it can be seen that the yield ratio is determined by the formation of these fine MAs.

[0083] Referring to FIG. 1, a photograph of a microstructure before a normalizing heat treatment of Test No. 1, an inventive example, it can be seen that sufficient bainite is secured, and, referring to FIG. 2, a photograph of a microstructure after a normalizing heat treatment of Test No. 1, an inventive example, it can be seen that fine and uniform MA is formed.

[0084] Referring to FIG. 3, which is a photograph of a microstructure after a normalizing heat treatment of Test No. 9, a comparative example, it can be seen that the carbon content is lower than that of polygonal ferrite, and the fraction of MA is significantly lowered.

[0085] In addition, referring to FIG. 4, which is a photograph of a microstructure after a normalizing heat treatment of Test No. 10, a comparative example, it can be seen that the Si content is lowered and the MA fraction is decreased.

[0086] While example embodiments have been shown and 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 disclosure as defined by the appended claims.

Claims

1. A low-yield ratio steel sheet having excellent low-temperature toughness, comprising, by weight, 0.05% to 0.1% of carbon (C), 0.3% to 0.7% of silicon (Si), 1.0% to 2.0% of manganese (Mn), 0.005% to 0.04% of aluminum (Al), 0.04% to 0.07% of niobium (Nb), 0.001% to 0.02% of titanium (Ti), 0.05% to 0.4% of copper (Cu), 0.1% to 0.6% of nickel (Ni), 0.01% to 0.08% of molybdenum (Mo), 0.001% to 0.008% of nitrogen (N), 0.015% or less of phosphorus (P), 0.003% or less of sulfur (S), a remainder of iron (Fe), and inevitable impurities,
   wherein a microstructure of the steel sheet comprises, by an area fraction, ferrite in an amount of 80 to 92% and MA (a mixed structure of martensite/austenite) in an amount of 8 to 20%,
   wherein the MA has an average size of 3 μm or less, when measured in equivalent circular diameter.

2. The low-yield ratio steel sheet according to claim 1, wherein, when a 100 μm-long straight line is drawn on the steel sheet, five (5) to thirteen (13) MA sites are present on the 100 μm-long straight line.

3. The low-yield ratio steel sheet according to claim 1, wherein the MA has a ratio of MA existing in ferrite grains and MA existing along ferrite grain boundaries ranging from 1:3 to 1:10.

4. The low-yield ratio steel sheet according to claim 1, wherein the ferrite has an average size of 20 μm or less measured in equivalent circular diameter.

5. The low-yield ratio steel sheet according to claim 1, wherein the steel sheet is a steel sheet treated by a normalizing heat treatment,
   before the normalizing heat treatment, the microstructure of the steel sheet comprises bainite in an amount of 50 area% to 90 area%.

6. The low-yield ratio steel sheet according to claim 1, wherein the steel sheet has a yield ratio of 0.5 to 0.65 and a low-temperature impact toughness of 100 J or greater at -40°C.

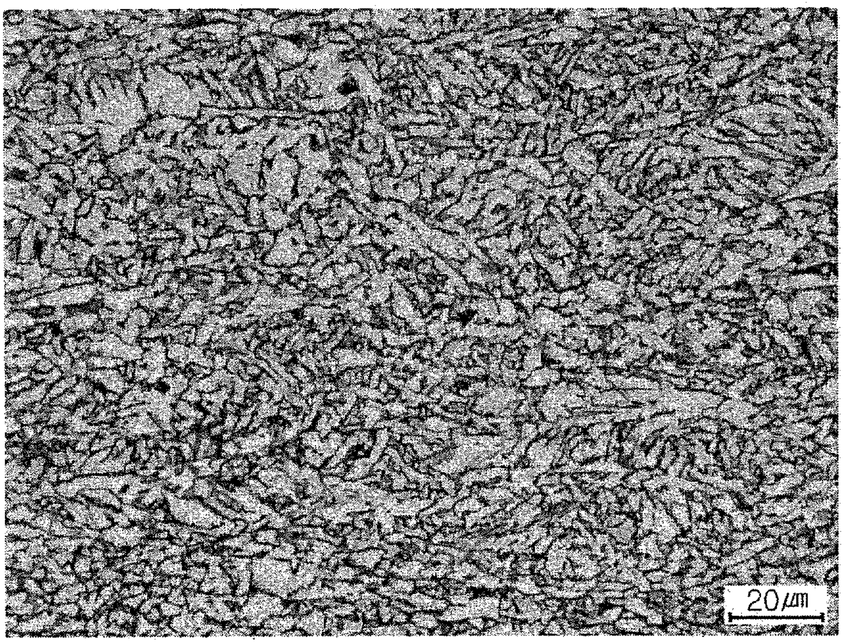
7. The low-yield ratio steel sheet according to claim 1, wherein the steel sheet has a yield strength of 350 MPa to 400 MPa and a tensile strength of 600 MPa or greater.

8. A method for manufacturing a low-yield ratio steel sheet having excellent low-temperature toughness, the method comprising:

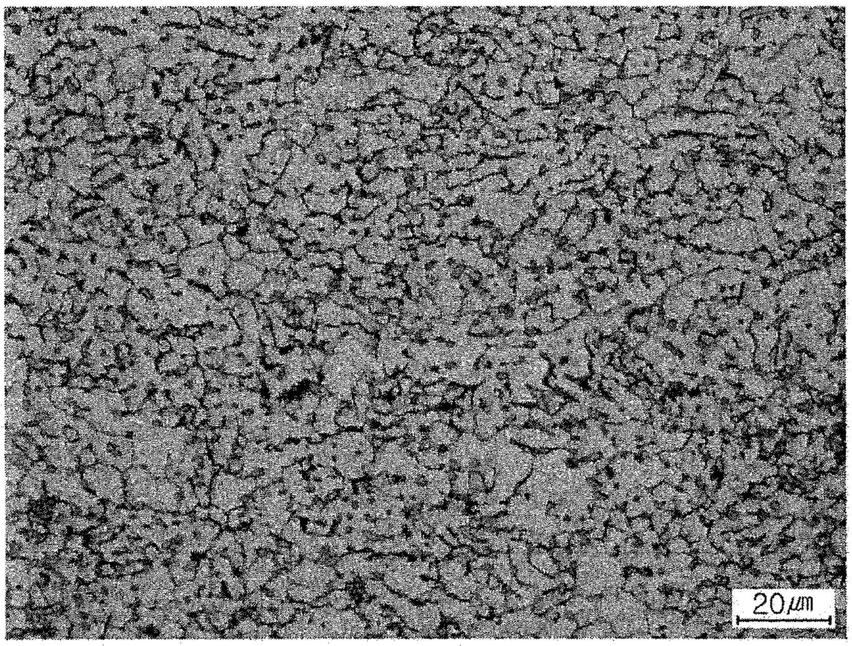
heating a slab to a temperature of 1050°C to 1200°C, the slab comprising, by weight, 0.05% to 0.1% of carbon (C), 0.3% to 0.7% of silicon (Si), 1.0% to 2.0% of manganese (Mn), 0.005% to 0.04% of aluminum (Al), 0.04% to 0.07% of niobium (Nb), 0.001% to 0.02% of titanium (Ti), 0.05% to 0.4% of copper (Cu), 0.1% to 0.6% of nickel (Ni), 0.01% to 0.08% of molybdenum (Mo), 0.001% to 0.008% of nitrogen (N), 0.015% or less of phosphorus (P), 0.003% or less of sulfur (S), a remainder of iron (Fe), and inevitable impurities;
hot rolling the heated slab in such a manner that a finish rolling termination temperature ranges from 760°C to 850°C, to obtain a hot-rolled steel sheet;
cooling the hot-rolled steel sheet to a temperature of 450°C or less at a cooling rate of 5°C/s or greater; and
after heating the cooled hot-rolled steel sheet to a temperature of 850°C to 960°C, performing a normalizing heat treatment maintaining the hot-rolled steel sheet for [1.3t+(10~30)] minutes, where t refers to a thickness of the hot-rolled steel sheet in millimeters (mm).

9. The method according to claim 8, wherein the cooled hot-rolled steel sheet has a microstructure comprising bainite in an amount of 50 area% to 90 area%.

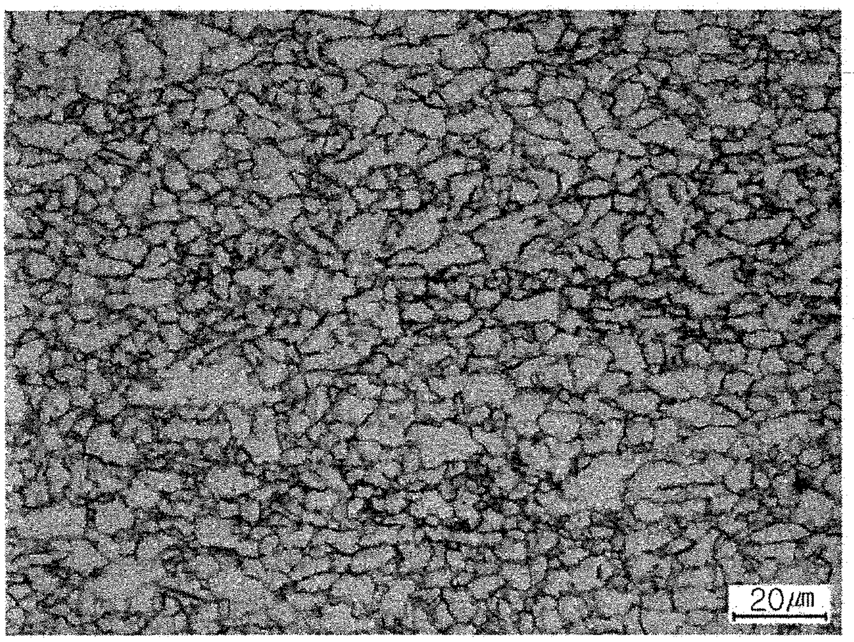
【Fig. 1】



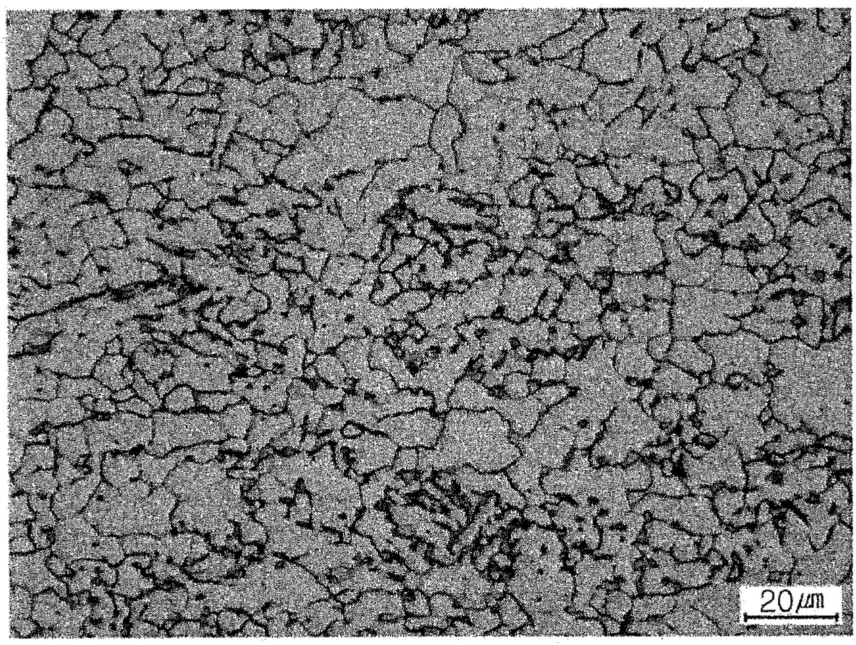
【Fig. 2】



【Fig. 3】



【Fig. 4】



INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2017/014411

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/04(2006.01)i, C22C 38/02(2006.01)i, C22C 38/06(2006.01)i, C22C 38/08(2006.01)i, C22C 38/12(2006.01)i, C22C 38/14(2006.01)i, C22C 38/16(2006.01)i, C21D 1/28(2006.01)i, C21D 8/02(2006.01)i, C21D 9/46(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/04; C21D 8/02; C22C 38/00; C21D 5/00; C21D 8/00; C22C 38/02; C22C 38/06; C22C 38/08; C22C 38/12; C22C 38/14; C22C 38/16; C21D 1/28; C21D 9/46

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: low yield ratio, ferrite, MA, austenite, bainite, normalizing, Nb, Ti, Cu, Ni, Mo

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 07-278656 A (NIPPON STEEL CORP.) 24 October 1995 See paragraphs [0006], [0011], [0013], [0021]-[0025], [0027], [0031] and claims 1-3.	1-9
A	KR 10-1412267 B1 (HYUNDAI STEEL COMPANY) 02 July 2014 See paragraphs [0063]-[0068] and claims 1-6.	1-9
A	JP 2003-003229 A (NIPPON STEEL CORP.) 08 January 2003 See paragraphs [0065]-[0067] and claims 1-5.	1-9
A	KR 10-2015-0065275 A (DOOSAN HEAVY INDUSTRIES & CONSTRUCTION CO., LTD.) 15 June 2015 See paragraphs [0056]-[0058] and claims 1-4.	1-9
A	JP 2002-105589 A (NATIONAL INSTITUTE FOR MATERIALS SCIENCE et al.) 10 April 2002 See paragraphs [0028], [0031] and claims 1-3.	1-9

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

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"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
20 FEBRUARY 2018 (20.02.2018)	**20 FEBRUARY 2018 (20.02.2018)**

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

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2017/014411

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- KR 20130076577 **[0009]**