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

(11) **EP 4 438 760 A1**

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

(43) Date of publication:
02.10.2024 Bulletin 2024/40

(21) Application number: **22899080.0**

(22) Date of filing: **25.11.2022**

(51) International Patent Classification (IPC):
C22C 38/04 *(2006.01)* ***C22C 38/08*** *(2006.01)*
C22C 38/06 *(2006.01)* ***C22C 38/02*** *(2006.01)*
C22C 38/12 *(2006.01)* ***C22C 38/14*** *(2006.01)*
C22C 38/00 *(2006.01)* ***C21D 8/02*** *(2006.01)*

(52) Cooperative Patent Classification (CPC):
C21D 8/02; C22C 38/00; C22C 38/02; C22C 38/04; C22C 38/06; C22C 38/08; C22C 38/12; C22C 38/14

(86) International application number:
PCT/KR2022/018814

(87) International publication number:
WO 2023/096398 (01.06.2023 Gazette 2023/22)

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

(30) Priority: **26.11.2021 KR 20210165471**

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(54) **STEEL PLATE HAVING EXCELLENT HEAT AFFECTED ZONE TOUGHNESS AND METHOD FOR MANUFACTURING SAME**

(57) The present invention relates to a steel plate for use in ships and the like, which has excellent toughness in a heat affected zone (HAZ) formed by welding, and to a method for manufacturing same.

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Description

Technical Field

[0001] The present disclosure relates to a steel material for use in ships and the like, which has excellent toughness in a weld heat-affected zone (HAZ) formed by welding, and to a method for manufacturing the same.

Background Art

[0002] Recently, as the northern sea ice area is rapidly decreasing due to an increase in temperatures due to global warming, interest in opening the northern sea route is increasing. It has been observed that the temperature in the northern region has risen by 3 to 4°C over the past 50 years, and an additional increase in temperatures of 6 to 7°C is expected over the next 100 years. Due to the increase in temperatures, summer northern sea ice has decreased by about 40% since 1980, and a thickness of sea ice is also becoming thinner, thereby increasing the possibility of utilizing the northern sea route.

[0003] It is necessary for ships to pioneer the northern sea route or to operate on the northern sea route to be built as icebreakers that can crush sea ice in the case of emergency. An icebreaker refers to a ship that sails by breaking ice on a surface of water to open a sea route.

[0004] Most icebreakers to date have been military or exploration ships, but as interest in the northern sea route increases, the scope of use thereof is expanding to include commercial ships and cruise ships (tourist ships). For example, Russia is the country that is most active in icebreaker construction due to regional characteristics. As of 2020, about 40 icebreakers are in operation worldwide, including the Ermak, Arktika, Sivir, and the like, and the construction of icebreakers is expected to increase further in the future.

[0005] Meanwhile, a steel material used in a hull of an icebreaker must have excellent impact toughness even at extremely low temperatures to withstand the low temperatures of the northern sea route, and at the same time, the steel material requires high strength to protect the hull.

[0006] It is advantageous for shipbuilders to increase an amount of heat input when welding steel materials to improve productivity when constructing icebreakers. However, when an amount of welding heat input is increased, a problem in which tensile strength and toughness of a weld heat-affected zone decrease occurs, so there is a demand for steel materials in which the toughness of the weld heat-affected zone does not decrease even if the heat input during welding is increased as described above.

[0007] In general, in order to secure the toughness of the weld heat-affected zone manufactured with high heat input, a method of refining a grain size of the weld heat-affected zone by increasing a nitrogen content to generate fine TiN precipitates is used (Patent Document 1). However, in this case, impact toughness of a base material is likely to decrease due to free nitrogen (free N) due to the high nitrogen content thereof, and as hardenability decreases due to the reduced grain size, the tensile strength of the weld heat-affected zone decreases, and when a large amount of low-temperature transformation phase is generated, a problem of deterioration in the toughness also occurs.

[0008] Accordingly, there is a need for a technology for manufacturing steel materials that can secure the strength and toughness of the base material while also securing excellent toughness in the weld heat-affected zone even when welding is performed with increased heat input.

[Prior art document]

[0009] (Patent Document 1) Japanese Patent Publication No. 2005-200716

Summary of Invention

Technical Problem

[0010] An aspect of the present disclosure is to provide a steel material capable of securing excellent toughness of a weld heat-affected zone, even when a steel material having high strength and high ductility is welded with a certain amount of heat input or more, and a method for manufacturing the same.

[0011] The subject of the present disclosure is not limited to the above. The subject of the present disclosure will be understood from the overall content of the present specification, and those of ordinary skill in the art to which the present disclosure pertains will have no difficulty in understanding the additional subject of the present disclosure.

Solution to Problem

[0012] According to an aspect of the present disclosure, a steel material having excellent toughness of a weld heat-affected zone is provided, the steel material including by weight: 0.04 to 0.07% of carbon (C), 1.5 to 1.7% of manganese (Mn), 0.1 to 0.3% of silicon (Si), 0.01 to 0.04% of aluminum (Al), 0.7 to 1.0% of nickel (Ni), 0.05 to 0.30% of molybdenum (Mo), 0.010 to 0.018% of titanium (Ti), 0.01 to 0.03% of niobium (Nb), 0.003 to 0.006% of nitrogen (N), 0.007% or less of phosphorus (P), 0.002% or less of sulfur (S), with a remainder of Fe and unavoidable impurities,
wherein a weld heat-affected zone (HAZ) welded with a heat input of 100 to 200KJ/cm includes a bainite phase in an area fraction of 90% or more in a region from a fusion line (FL) to FL+3mm.

[0013] According to another aspect of the present disclosure, a method for manufacturing a steel material having excellent toughness of a weld heat-affected zone is provided, the method including: reheating a steel slab having the above-described alloy composition to a temperature within a range of 1100 to 1180°C; rough rolling the heated steel slab in a temperature range of 900°C or higher; finishing rolling the steel slab in a temperature range of 800°C or higher after the rough rolling to prepare a hot-rolled steel material; and cooling the hot-rolled steel material until the temperature at t/4 point of the thickness (t, unit of mm) of the hot-rolled steel material is 600°C or lower at a cooling rate of 10°C/s or more.

Advantageous Effects of Invention

[0014] As set forth above, according to the present disclosure, a steel material that not only has excellent strength and toughness of a base material, but also may secure excellent strength and toughness in a weld heat-affected zone, and a method of manufacturing the same may be provided. The steel material described above may be applied in various fields such as icebreakers, structures in extremely low-temperature environments.

[0015] The various and beneficial advantages and effects of the present invention are not limited to the above-described content, and may be more easily understood through description of specific embodiments of the present disclosure.

Best Mode for Invention

[0016] Terms used in the present specification are for explaining specific exemplary embodiments rather than limiting the present disclosure. In addition, a singular form used in the present specification includes a plural form also, unless the relevant definition has a clearly opposite meaning thereto.

[0017] The meaning of "comprising" used in the specification is to embody the configuration and is not to exclude the presence or addition of other configurations.

[0018] Unless otherwise defined, all terms including technical terms and scientific terms used in the present specification have the same meaning as would be commonly understood by a person with ordinary skill in the art to which the present disclosure pertains. Pre-defined terms are interpreted as being consistent with the relevant technical literature and the disclosure herein.

[0019] The present inventor of the present disclosure has studied in detail a technology for improving toughness formed in a weld heat-affected zone, particularly, low-temperature toughness, when welding with a medium heat input of about 100 to 200kJ/cm is performed on the steel material having high strength and toughness by increasing a welding heat input.

[0020] As a result thereof, the present inventor has confirmed that the technical purpose of the present disclosure may be achieved by controlling a grain size while securing a structure near a fusion line (FL) of the weld heat-affected zone as a hard state by optimizing an alloy composition and manufacturing conditions, thereby resulting in completion of the present disclosure.

[0021] Hereinafter, the present disclosure will be described in detail.

[0022] The steel material having excellent weld heat-affected zone toughness according to the present disclosure may be configured to have an alloy composition by weight: 0.04 to 0.07% of carbon (C), 1.5 to 1.7% of manganese (Mn), 0.1 to 0.3% of silicon (Si), 0.01 to 0.04% of aluminum (Al), 0.7 to 1.0% of nickel (Ni), 0.05 to 0.30% of molybdenum (Mo), 0.010 to 0.018% of titanium (Ti), 0.01 to 0.03% of niobium (Nb), 0.003 to 0.006% of nitrogen (N), 0.007% or less of phosphorus (P), and 0.002% or less of sulfur (S).

[0023] Hereinafter, a reason for limiting an alloy composition of the steel material provided in the present disclosure as described above will be described in detail.

[0024] Meanwhile, in the present disclosure, unless specifically stated, a content of each element is based on weight, and a ratio of a structure is based on area.

Carbon (C): 0.04 to 0.07%

[0025] Carbon (C) is the most important element in securing strength of not only a base material but also of a weld

heat-affected zone, so it needs to be contained in steel within an appropriate range.

[0026] If the C content exceeds 0.07%, hardenability improves, the strength increases excessively, and there is a problem in that toughness of the weld heat-affected zone decreases due to precipitation of fine hard phases. On the other hand, if the C content is less than 0.04%, it is preferable because it causes a decrease in strength.

[0027] Therefore, C may be included in an amount of 0.04 to 0.07%. More advantageously, C may be included in an amount of 0.045% or more and 0.065% or less.

Manganese (Mn): 1.5 to 1.7%

[0028] Manganese (Mn) is a useful element for improving strength through solid solution strengthening and increasing hardenability to form a low-temperature transformation phase.

[0029] In the present disclosure, since the strength of the weld heat-affected zone is intended to be secured to 610 MPa or more, to this end, Mn is preferably included in an amount of 1.5% or more. However, if the Mn content exceeds 1.7%, the hardenability increases excessively and there is a risk that the toughness of the weld heat-affected zone will be greatly reduced.

[0030] Therefore, in the present disclosure, Mn may be included in an amount of 1.5 to 1.7%.

Silicon (Si): 0.1 to 0.3% and Aluminum (Al): 0.01 to 0.04%

[0031] Silicon (Si) and Aluminum (Al) are essential elements for deoxidation by precipitating dissolved oxygen in molten steel in a form of slag during a steelmaking and continuous casting process. When manufacturing a steel material using a converter, Si is preferably included in an amount of 0.1% or more, and Al is preferably included in an amount of 0.01% or more. However, if the content of Si and Alis excessive, since there is a risk that a coarse composite oxide of Si and Al may be generated or a large amount of fine hard phases may be generated in a microstructure of the weld heat-affected zone, Si is preferably included in an amount of 0.3% or less and Al is preferably included in an amount of 0.04% or less.

Nickel (Ni): 0.7 to 1.0%

[0032] Nickel (Ni) is an important element improving impact toughness by facilitating cross slip of dislocations at low temperatures and increasing strength by increasing hardenability.

[0033] The present disclosure intends to form a hard phase (preferably a bainite phase) near a fusion line in a weld heat-affected zone, and Ni is preferably included in an amount of 0.7% or more in order to improve the impact toughness in this hard phase structure.

[0034] However, if the Ni content exceeds 1.0%, there is a problem that the hardenability is excessive and the toughness is lowered, and manufacturing costs are also greatly increased. Therefore, in the present disclosure, Ni may be included in an amount of 0.7 to 1.0%.

Molybdenum (Mo): 0.05 to 0.30%

[0035] Molybdenum (Mo) is an element useful for increasing strength by improving hardenability of steel, and Mo is preferably included in an amount of 0.05% or more to secure the strength targeted in the present disclosure. However, if the Mo content is excessive, the strength may increase excessively and there is a risk that toughness may decrease, so Mo is preferably included not to exceed 0.30%.

Titanium (Ti): 0.010 to 0.018%

[0036] Titanium (Ti) precipitates as TiN when reheated and suppresses grain growth in a base material and weld heat-affected zone, thereby significantly improving toughness. In order to effectively precipitate TiN, Ti is preferably included in an amount of 0.010% or more. However, if the Ti content exceeds 0.018%, there is a problem in that low-temperature toughness deteriorates due to clogging of a casting nozzle or crystallization in a center portion, and a content ratio of Ti and N(N/Ti) decreases, and TiN precipitates become coarse, there is a risk that the toughness of the weld heat-affected zone may decrease.

[0037] Therefore, in the present disclosure, Ti may be included in an amount of 0.010 to 0.018%.

Niobium (Nb): 0.01 to 0.03%

[0038] Niobium (Nb) is precipitated into a form of NbC or NbCN to improve strength of a base material. In addition,

Nb dissolved in solid solution when reheated to a high temperature precipitates very finely in a form of NbC during rolling, which has an effect of suppressing recrystallization of austenite and refining the structure.

[0039] In order to sufficiently obtain the above-described effect, Nb is preferably included in an amount of 0.01% or more. However, if the Nb content exceeds 0.03%, there is a high possibility that brittle cracks may be caused at an edge of the steel material, and a large amount of fine hard phases is generated, so that there is a risk that toughness may decrease.

[0040] Therefore, in the present disclosure, Nb may be included in an amount of 0.01 to 0.03%.

Nitrogen (N): 0.003 to 0.006%

[0041] Nitrogen (N) combines with Ti and precipitates as TiN, thereby suppressing growth of prior austenite grains, thereby exhibiting an effect of refining a grain size. As described above, in order to form fine TiN precipitates, N is preferably included in an amount of 0.003% or more. However, if the N content exceeds 0.006%, not only does toughness deteriorate due to generation of free nitrogen (free N), but also there is a problem that AlN precipitates and causes slab cracks.

[0042] Accordingly, N may be included in an amount of 0.003 to 0.006%, and more advantageously, N may be included in an amount of 0.004% or more and 0.005% or less.

Phosphorus (P): 0.007% or less and Sulfur (S): 0.002% or less

[0043] Phosphorus (P) and Sulfur (S) are elements causing brittleness of grain boundaries or by forming coarse inclusions to cause brittleness. For the purpose of improving resistance to brittle crack propagation of a steel material, P may be limited to 0.007% or less, and S may be limited to 0.002% or less.

[0044] It is preferable to have 0% of these elements, but considering that these elements may inevitably be added, 0% may be excluded.

[0045] A remainder of the present disclosure may be iron (Fe). However, in a general manufacturing process, inevitable impurities may be inevitably added from raw materials or an ambient environment, and thus, impurities may not be excluded. A person skilled in the art of a general manufacturing process may be aware of the impurities, and thus, the descriptions of the impurities may not be provided in the present disclosure.

[0046] The steel material of the present disclosure having the above-described alloy composition may be composed of a single phase of bainite, bainite in an area fraction of 90% or more, and residual acicular ferrite, as a microstructure, and therefrom, the steel material has a tensile strength of 610 to 770 MPa, and impact toughness of 33J or more at - 20°C.

[0047] Meanwhile, it is preferable that the weld heat-affected zone formed by welding the steel material of the present disclosure with a medium heat input (about 100 to 200 kJ/cm) includes a bainite phase in an area fraction of 90% or more in a region from a fusion line (FL) to FL+3mm.

[0048] If the bainite phase in the region of the fusion line is less than 90%, a target level of strength may not be secured.

[0049] The region of the fusion line may be a single-phase of bainite, but may also include an acicular ferrite phase in addition to bainite. In addition, a trace amount of the MA phase may be included in the bainite phase and the acicular ferrite structure, and it should be noted that the MA phase contained in this case is at a level that does not impair physical properties of the fusion line.

[0050] In addition, it is preferable that an average grain size of prior austenite from the fusion line (FL) to FL + 3 mm region is 100 pm or less. As described above, by refining the grain size in the fusion line region, the target level of strength and toughness may be advantageously secured.

[0051] Specifically, the region from the fusion Line (FL) to FL+3 mm has a tensile strength of 610 MPa or more and impact toughness of 33 J or more at -20°C, illustrating excellent strength and low-temperature toughness.

[0052] Hereinafter, a method for manufacturing a steel material with excellent weld heat-affected zone toughness according to another aspect of the present disclosure will be described in detail.

[0053] The steel material of the present disclosure may be manufactured through a process of reheating a steel slab satisfying the above-described composition, performing rough rolling and finishing rolling the steel slab, and then cooling the steel slab. Hereinafter, each process is described in detail.

Reheating slab: 1100 to 1180°C

[0054] It is preferable to reheat the steel slab satisfying the above-described alloy composition to a temperature in a range of 1100 to 1180°C. It is preferable to set the reheating temperature to 1100°C or higher to sufficiently dissolve carbonitrides of Ti and/or Nb formed during continuous casting. However, when reheated to an excessively high temperature, there is a risk that austenite may coarsen, so the reheating temperature is preferably 1180°C or lower.

Rough rolling: 900°C or higher

[0055] The reheated steel slab is subjected to rough rolling to adjust a shape of the steel slab. The rough rolling temperature is preferably higher than a temperature (Tnr) at which austenite recrystallization stops, and accordingly, the rough rolling is preferably performed in a temperature range of 900°C or higher. An effect of reducing the grain size may also be achieved through recrystallization of coarse austenite along with destruction of a casting structure such as dendrites, or the like, formed during casting by rolling.

[0056] In order to cause sufficient recrystallization and refine the structure during rough rolling at the above-described temperature, it is preferable that a total cumulative reduction ratio during rough rolling is 40% or more.

Finishing rolling: 800°C or higher

[0057] In order to introduce an austenite structure of the rough-rolled steel sheet into a non-uniform microstructure, finishing rolling is performed to manufacture a hot-rolled steel material. Specifically, it is preferable that the finishing rolling is performed in a temperature range of 800°C or higher in order to provide maximum deformation in the structure. If the finishing rolling temperature is less than 800°C, ferrite precipitates during cooling after completion of rolling and the strength decreases, so finishing rolling is preferably performed in a temperature range of 800°C or higher.

[0058] In order to create a fine structure as possible during finishing rolling at the above-described temperature, the cumulative reduction ratio of the finishing rolling is preferably 50% or more.

[0059] Cooling after rolling: cooling is performed until the temperature at t/4 point of the thickness (t, unit of mm) of the hot-rolled steel material is 600°C or lower at a cooling rate of 10°C/s or more.

[0060] When cooling the hot-rolled steel material prepared as above, when the cooling rate is less than 10°C/s or a cooling end temperature exceeds 600°C, there is a risk that a microstructure of a base material affecting the microstructure of the weld heat-affected zone formed by subsequent welding may become coarse. An upper limit of the cooling rate is not specifically limited in the present disclosure, but in the technical field to which the present disclosure pertains, the cooling rate may be 100°C/s or more, so as a preferred example, the cooling rate is preferably 200°C/s or less. In the present disclosure, the cooling end temperature is not particularly limited, and it should be noted that the cooling is performed to room temperature.

[0061] The cooled hot-rolled steel material may be welded, and the welding may be performed with a medium heat input, for example, may be performed with a heat input of 100 to 200 KJ/cm. In this case, any welding method may be used as long as it is a welding method that the above-described heat input may be applied. A non-limiting example may be EGW.

[0062] When the hot-rolled steel material according to the present disclosure is welded with a medium heat input, the formed weld heat-affected zone has a fine structure in which the region of the fusion line is mainly composed of a bainite phase, and thus the hot-rolled steel material has excellent low-temperature toughness as well as strength.

[0063] Hereinafter, the present disclosure will be described in more detail through examples. However, it should be noted that the following examples are for illustrative purposes only and are not intended to limit the scope of the present disclosure. The scope of the present disclosure may be determined by matters described in the claims and matters able to be reasonably inferred therefrom.

Mode for Invention

[0064] A steel slab having a thickness of 300 mm having the composition shown in Table 1 (a remainder of Fe and unavoidable impurities) was reheated to a temperature of 1140°C, and was then continuously subjected to rough rolling in a temperature range of 980°C, and was finished with finishing rolling in a temperature range of 880°C. Thereafter, the steel slab was cooled until the temperature at a 1/4t point reaches a temperature in a range of 470 to 580°C at a cooling rate of 16 to 35°C/s, to prepare a steel material. In this case, the rough rolling was performed at a reduction rate of 40% or more, and the finishing rolling was performed at a cumulative reduction rate of 50% or more.

[0065] For the steel material prepared as above, a microstructure thereof was measured and the results thereof were shown in Table 2.

[0066] In addition, for the steel material prepared according to the above, welding was performed with a heat input of 100 to 200 KJ/cm, where a microstructure of a region from a fusion line (FL) to FL+3 mm of a weld heat-affected zone and mechanical properties (tensile strength, low-temperature impact toughness) were analyzed and the results were shown in Table 2.

[0067] The microstructure of the steel material(base material) and the fusion line was observed using an optical microscope, and then classified using EBSD equipment, and a fraction thereof was measured.

[0068] The tensile strength of the steel material(base material) and the fusion line was measured using a universal tensile machine, and the low-temperature impact toughness was measured through a Charpy impact absorption energy

(CVN) value at -20°C using a Charpy impact tester.

[Table 1]

Steel type	Alloy composition (weight %)										
	C	Mn	Si	Al	Ni	Mo	Nb	Ti	N*	P*	S*
Inventi ve Steel 1	0.049	1.64	0.16	0.02	0.89	0.13	0.012	0.013	58	65	9
Inventi ve Steel 2	0.043	1.58	0.21	0.03	0.92	0.08	0.019	0.017	48	52	13
Inventi ve Steel 3	0.056	1.68	0.11	0.02	0.76	0.16	0.023	0.013	39	47	12
Inventi ve Steel 4	0.062	1.52	0.24	0.03	0.83	0.22	0.019	0.011	52	49	15
Compara tive Steel 1	0.093	1.66	0.16	0.03	0.91	0.32	0.016	0.015	49	68	12
Compara tive Steel 2	0.047	1.42	0.19	0.03	0.71	0.17	0.014	0.012	51	61	9
Compara tive Steel 3	0.061	1.54	0.23	0.02	0.58	0.12	0.017	0.014	49	53	8
Compara tive Steel 4	0.056	1.66	0.13	0.02	0.85	0.13	0.007	0.021	22	53	11
N*, P* and S* are expressed in ppm.											

[Table 2]

Steel type	Base material microstructur e (fraction %)		Weldin g heat input (KJ/ cm)	FL to FL+3mm microstructure (fraction %)		FL to +FL+3mm average AGS (μm)	FL to +FL+3mm tensile strength (MPa)	FL to +FL+3mm impact toughness (-20°C,
	B	AF		B	remain der			
Inventiv e Steel 1	98	2	135	97	AF	91	635	59
Inventiv e Steel 2	100	-	168	93	AF	88	623	43
Inventiv e Steel 3	100	-	187	96	AF	97	619	59
Inventiv e Steel 4	95	5	156	92	AF	92	621	82
Comparat ive Steel 1	100	-	163	100	-	87	679	17
Comparat ive Steel 2	78	22	175	67	AF+PF	97	572	63
Comparat ive Steel 3	74	26	166	85	AF	89	598	13
Comparat ive Steel 4	98	2	171	96	AF	129	612	29
B is bainite, AF is acicular ferrite, and PF is polygonal ferrite.								

[0069] As illustrated in Tables 1 to 3, in Inventive Examples 1 to 4, satisfying all of the alloy composition and manufacturing conditions limited by the present disclosure, it can be confirmed that Inventive Steels 1 to 4 have excellent strength and low-temperature toughness of a weld heat-affected zone. In particular, it can be seen that the weld heat-affected zone of Inventive steels described above has a tensile strength of 610 MPa or more and an impact toughness of 33 J or more at -20°C.

[0070] On the other hand, in Comparative Example 1 having an excessive content of C and Mo among the alloy compositions limited by the present disclosure had inferior impact toughness as the strength of the weld heat-affected

zone is excessively higher as compared to that of Inventive Steel.

[0071] Comparative Example 2 illustrates a case in which a Mn content was insufficient, and in Comparative Example 2, the strength of the weld heat-affected zone was inferior as a bainite phase was not sufficiently formed of the weld heat-affected zone.

[0072] In Comparative Example 3, the low-temperature toughness of the weld heat-affected zone was significantly inferior due to an insufficient Ni content, and specifically, the low-temperature toughness thereof was 13J at -20°C.

[0073] Comparative Example 4 illustrates a case in which a Ti content is excessive, but N and Nb contents are insufficient, and as a result, in Comparative Example 4, coarse TiN was precipitated in a weld zone, and a particle refinement effect due to NbC was insufficient, so that a grain size of prior austenite was coarse, and as a result thereof, low-temperature toughness was inferior.

Claims

1. A steel material having excellent weld heat-affected zone toughness, comprising by weight:

   0.04 to 0.07% of carbon (C), 1.5 to 1.7% of manganese (Mn), 0.1 to 0.3% of silicon (Si), 0.01 to 0.04% of aluminum (Al), 0.7 to 1.0% of nickel (Ni), 0.05 to 0.30% of molybdenum (Mo), 0.010 to 0.018% of titanium (Ti), 0.01 to 0.03% of niobium (Nb), 0.003 to 0.006% of nitrogen (N), 0.007% or less of phosphorus (P), 0.002% or less of sulfur (S), a balance of Fe, and unavoidable impurities,
   wherein a weld heat-affected zone (HAZ) welded with a heat input of 100 to 200KJ/cm includes a bainite phase of an area fraction of 90% or more in a region from a fusion line (FL) to FL+3mm.

2. The steel material having excellent weld heat-affected zone toughness of claim 1, wherein an average grain size of prior austenite in the region from the fusion line (FL) to FL+3mm is 100pm or less.

3. The steel material having excellent weld heat-affected zone toughness of claim 1, wherein the region from the fusion line (FL) to FL+3mm has a tensile strength of 610 MPa or more and an impact toughness of 33J or more at -20°C.

4. The steel material having excellent weld heat-affected zone toughness of claim 1, wherein the steel material comprises bainite in an area fraction of 90% or more (including 100%) and residual acicular ferrite as a microstructure.

5. A method for manufacturing a steel material having excellent weld heat-affected zone toughness, comprising:

   reheating a steel slab including by weight: 0.04 to 0.07% of carbon (C), 1.5 to 1.7% of manganese (Mn), 0.1 to 0.3% of silicon (Si), 0.01 to 0.04% of aluminum (Al), 0.7 to 1.0% of nickel (Ni), 0.05 to 0.30% of molybdenum (Mo), 0.010 to 0.018% of titanium (Ti), 0.01 to 0.03% of niobium (Nb), 0.003 to 0.006% of nitrogen (N), 0.007% or less of phosphorus (P), 0.002% or less of sulfur (S), a balance of Fe, and unavoidable impurities, in a temperature range of 1100 to 1180°C;
   rough rolling the heated steel slab in a temperature range of 900°C or higher;
   finishing rolling the steel slab in a temperature range of 800°C or higher after the rough rolling to prepare a hot-rolled steel material; and
   cooling the hot-rolled steel material until the temperature at t/4 point of the thickness (t, unit of mm) of the hot-rolled steel material is 600°C or lower at a cooling rate of 10°C/s or more.

6. The method for manufacturing a steel material having excellent weld heat-affected zone toughness of claim 5, wherein the rough rolling is performed at a reduction ratio of 40% or more.

7. The method for manufacturing a steel material having excellent weld heat-affected zone toughness of claim 5, wherein the finish rolling is performed at a cumulative reduction ratio of 50% or more.

8. The method for manufacturing a steel material having excellent weld heat-affected zone toughness of claim 5, further comprising: welding the hot-rolled steel material after the cooling,
   wherein the welding is performed with a heat input of 100 to 200 KJ/cm.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2022/018814

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/04(2006.01)i; **C22C 38/08**(2006.01)i; **C22C 38/06**(2006.01)i; **C22C 38/02**(2006.01)i; **C22C 38/12**(2006.01)i; **C22C 38/14**(2006.01)i; **C22C 38/00**(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 38/04(2006.01); B21B 3/00(2006.01); C21D 8/02(2006.01); C22C 38/00(2006.01); C22C 38/14(2006.01); C22C 38/16(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: 용접(welding), 열영향부(heat affected zone), 강재(steel), 열간압연(heat rolling), 냉각(cooling), 입열량(heat input)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2011-038172 A (NIPPON STEEL CORP.) 24 February 2011 (2011-02-24) See claims 1-3.	5-7
Y		1-4,8
Y	KR 10-2020-0064510 A (POSCO) 08 June 2020 (2020-06-08) See claim 8.	1-4,8
X	KR 10-2017-0075867 A (POSCO) 04 July 2017 (2017-07-04) See claim 5.	5-7
X	JP 4897126 B2 (NIPPON STEEL CORP.) 14 March 2012 (2012-03-14) See paragraph [0035]; and claims 1 and 3.	5-7
A	JP 2014-095146 A (JFE STEEL CORP.) 22 May 2014 (2014-05-22) See paragraphs [0013]-[0025].	1-8

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

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

Date of the actual completion of the international search	Date of mailing of the international search report
02 March 2023	**02 March 2023**
Name and mailing address of the ISA/KR **Korean Intellectual Property Office** **Government Complex-Daejeon Building 4, 189 Cheongsa-ro, Seo-gu, Daejeon 35208** Facsimile No. **+82-42-481-8578**	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2022/018814

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JP 4897126 B2	14 March 2012	BR 112012024297 A2	24 May 2016
		BR 112012024297 B1	12 February 2019
		WO 2011-148754 A1	01 December 2011
JP 2014-095146 A	22 May 2014	JP 6036616 B2	30 November 2016

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

REFERENCES CITED IN THE DESCRIPTION

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