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(54) **THICK STEEL PLATE HAVING EXCELLENT LOW-TEMPERATURE STRAIN AGING IMPACT PROPERTY AND MANUFACTURING METHOD THEREFOR**

(57) The present invention relates to a thick steel plate superior in low-temperature strain aging impact properties and a manufacturing method therefor and, more particularly, to a thick steel plate that is usable as a material in ship building, marine structures, and the like and which has excellent low-temperature strain aging impact properties and a method for manufacturing the same. An embodiment of the present invention provides a thick steel plate having excellent low-temperature strain aging impact properties, the steel plate comprising, by weight: 0.04-0.1% of C; 0.05-0.4% of Si; 1.0-2.0% of Mn; 0.01% or less of P; 0.003% or less of S; 0.015-0.04% of Al; 0.005-0.02% of Ti; 0.35% or less (0 exclusive) of Cu; 0.05-0.8% of Ni; 0.003-0.03% of Nb; 0.002-0.008% of N; 0.0002-0.0050% of Ca; 0.009% or less of Cr; 0.0009% or less of Mo; and a balance of Fe and other inevitable impurities, with the microstructure thereof including 95% by area or greater of ferrite 10  $\mu$ m or less in average grain size, and a manufacturing method therefor.

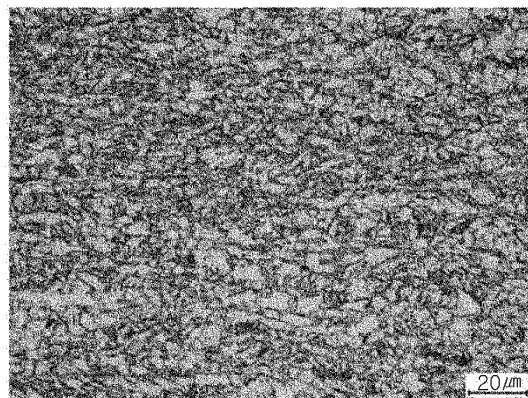


FIG. 1

**Description**

[Technical Field]

5     **[0001]** The present disclosure relates to a thick steel plate having excellent low-temperature strain aging impact properties and a manufacturing method therefor, and more particularly, to a thick steel plate having excellent low-temperature strain aging impact properties, that may be used as a material in ship building, marine structures, and the like, and a manufacturing method therefor.

10     [Background Art]

15     **[0002]** Recently, mining areas have gradually moved to deep-sea areas or cold areas due to the depletion of land or offshore energy resources. Accordingly, boring, mining, and storage facilities are increasingly complicated due to the enlargement, integration, and the like of the facilities. Steel materials used therein are required to have excellent low-temperature toughness for securing stability of the structure, and, in particular, required to minimize the decrease in toughness due to a strain aging phenomenon by a cold working in a manufacturing process of the structure, or the like.

20     **[0003]** In general, the strain aging impact properties are evaluated by subjecting a steel plate to several percent of tensile strain, aging the steel plate at about 250°C for 1 hour, processing the aged steel plate to make an impact specimen, and then performing an impact test on the impact specimen. The more severe the strain aging phenomenon, the faster the toughness of the steel plate decreases, and the decrease in toughness may also increase. In this case, the lifespan of the site and the structure to which the steel plate is applied may be reduced and stability may be affected. Therefore, in recent years, a steel plate having high resistance to the strain aging phenomenon has been required for the purpose of increasing the lifespan of the steel plate subjected to strain to increase the stability of the structure.

25     **[0004]** Deterioration in impact toughness by the strain aging phenomenon may occur when yield strength is greater than breaking strength. In other words, the greater the difference between yield strength and breaking strength, the greater the amount of strain of the steel materials in ductility, and the absorbed impact energy may increase. Therefore, when cold deformation is performed to apply the steel materials to the structure, the yield strength of the steel materials may increase, to decrease the difference between the yield strength and the breaking strength, which is accompanied by a decrease in impact toughness.

30     **[0005]** The decrease in toughness due to the increase in yield strength may be caused by subjecting strain of the steel materials to fix interstitial elements in the steel materials such as C, N, and the like to the dislocation over time.

35     **[0006]** In order to prevent the decrease in toughness by cold deformation, conventionally, a method of significantly decreasing the amount of carbon (C) or nitrogen (N) dissolved in the steel materials for suppressing strength increase by an aging phenomenon after deformation, a method of adding an element such as nickel (Ni), or the like to lower stacking fault energy to facilitate the movement of dislocations, and the like have been applied. Alternatively, a method of performing stress relief heat treatment after cold deformation to decrease dislocation and the like produced in the steel materials, thereby lowering the yield strength increased by work hardening, has been used, and, as an example thereof, Non-Patent Document 1 below is disclosed.

40     **[0007]** However, as structures and the like are continuously becoming larger and more complicated, the cold deformation amount required for the steel material is increased, and also the temperature of a use environment is lowered to the temperature level of arctic sea. Thus, it is difficult to effectively prevent a toughness decrease by strain aging of the steel material, with conventional methods.

45     **[0008]** (Non-Patent Document 1) The effect of processing variables on the mechanical properties and strain ageing of high-strength low-alloy V and VN steels (VK Heikkinen and JD Boyd, CANADIAN METALLURGICAL QUARTERLY Volume 15 Number 3 (1976), P. 219~)

[Disclosure]

[Technical Problem]

50     **[0009]** An aspect of the present disclosure is to provide a thick steel plate having excellent low-temperature strain aging impact properties and a manufacturing method therefor.

[Technical Solution]

55     **[0010]** According to an aspect of the present disclosure, a thick steel plate having excellent low-temperature strain aging impact properties, includes: by weight, C: 0.04 to 0.1%, Si: 0.05 to 0.4%, Mn: 1.0 to 2.0%, P: 0.01% or less, S: 0.003% or less, Al: 0.015 to 0.04%, Ti: 0.005 to 0.02%, Cu: 0.35% or less (excluding O), Ni: 0.05 to 0.8%, Nb: 0.003 to

0.03%, N: 0.002 to 0.008%, Ca: 0.0002 to 0.0050%, Cr: 0.009% or less, Mo: 0.0009% or less, a balance of Fe and other inevitable impurities, and comprising 95 area% or more of ferrite having an average grain size of 10 $\mu$ m or less as a microstructure.

**[0011]** According to an aspect of the present disclosure, a method of manufacturing a thick steel plate having excellent low-temperature strain aging impact properties, includes: reheating a steel slab including, by weight, C: 0.04 to 0.1%, Si: 0.05 to 0.4%, Mn: 1.0 to 2.0%, P: 0.01% or less, S: 0.003% or less, Al: 0.015 to 0.04%, Ti: 0.005 to 0.02%, Cu: 0.35% or less (excluding 0), Ni: 0.05 to 0.8%, Nb: 0.003 to 0.03%, N: 0.002 to 0.008%, Ca: 0.0002 to 0.0050%, Cr: 0.009% or less, Mo: 0.0009% or less, a balance of Fe and other inevitable impurities, at 1020 to 1150°C; performing a recrystallization zone rolling operation of the reheated steel slab in 5 passes or less (including 0 passes) to obtain a bar; and performing a non-recrystallization zone rolling operation on the bar at Ar3 or higher to obtain a hot-rolled steel material.

[Advantageous Effects]

**[0012]** According to an aspect of the present disclosure, a thick steel plate having excellent low-temperature strain aging impact properties and excellent yield strength may be provided.

[Description of Drawings]

**[0013]**

FIG. 1 is a captured photograph of a microstructure of Inventive Example 1 according to an embodiment of the present disclosure.

FIG. 2 is a captured photograph a microstructure of Comparative Example 1 according to an embodiment of the present disclosure.

[Best Mode for Invention]

**[0014]** Hereinafter, the present disclosure will be described in detail. First, the alloy composition of the present disclosure will be described. The content of the alloy composition described below means by weight.

Carbon (C): 0.04-0.1%

**[0015]** In the present disclosure, C may be an element which is effective for a solid solution strengthening, and may be present as carbonitride by Nb, and the like, to secure tensile strength. In order to obtain the effect, the C content may be 0.04% or more. When the C content exceeds 0.1%, not only may formation of a martensite-austenite (MA) be promoted, but pearlite may also be generated to deteriorate impact and fatigue properties at low temperatures. In addition, since strain aging impact properties decrease as an amount of solid solution C increases, the C content may be in the range of 0.04 to 0.1%. More preferably, the C content may be in the range of 0.04 to 0.08% in order to more stably secure toughness at low temperature.

Silicon (Si): 0.05-0.4%

**[0016]** Si may be an element necessary for assisting Al to deoxidize molten steel, and to secure yield and tensile strength. The Si content may be in the range of 0.4% or less to secure impact and fatigue properties at low temperatures. In addition, when the Si content exceeds 0.4%, Si may prevent diffusion of C to promote formation of the MA. In order to control the Si content to 0.05% or less, there may be a disadvantage in that a treatment time in a steelmaking process may greatly increase. Therefore, the Si content may be in the range of 0.05 to 0.4%. The Si content is more preferably in the range of 0.05 to 0.2% in order to more stably secure toughness by minimizing the formation of MA.

Manganese (Mn): 1.0-2.0%

**[0017]** Mn may be added in an amount of 1.0% or more, since Mn has a relatively large effect on an increase in strength by solid solution strengthening. When the Mn content exceeds 2.0%, since toughness may be deteriorated due to formation of MnS inclusions or segregation of a central portion, the Mn content may be in the range of 1.0 to 2.0%. The Mn content is more preferably in the range of 1.3 to 1.7% in consideration of an effect of increasing strength and a decrease in toughness due to the segregation.

Phosphor (P): 0.01% or less

**[0018]** Since P may be an element causing grain boundary segregation and may cause embrittlement of steel, an upper limit thereof needs to be limited to 0.01%.

Sulfur (S): 0.003% or less

**[0019]** S may be mainly combined with Mn to form MnS inclusions, factors decreasing toughness at low temperature. Therefore, in order to secure toughness at low temperature and fatigue properties at low temperature, it is necessary to limit the S content to 0.003% or less.

Aluminum (Al): 0.015-0.04%

**[0020]** In the present disclosure, Al may be not only a major deoxidizer of steel, but also an element necessary for fixing N during strain aging. In order to fully acquire the effect, Al may be added 0.015% or more. When Al exceeds 0.04%, a fraction and a size of  $Al_2O_3$  inclusions may increase to cause a decrease in the toughness at low temperature. In addition, similar to Si, since the formation of MA in a base material and a weld heat affected zone promotes to deteriorate the toughness at low temperature and the fatigue properties at low temperature, the Al content may be in the range of 0.015 to 0.04%. Al is more preferably in the range of 0.015 to 0.025% in order to more stably secure the toughness by minimizing the formation of MA.

Titanium (Ti): 0.005-0.02%

**[0021]** Ti may be an element that reduces solid solution N by forming Ti nitride (TiN) in combination with N causing strain aging. The Ti nitride may serve to contribute to miniaturization by inhibiting coarsening of a microstructure, and to improve toughness. In order to obtain the effect, Ti may be added in an amount of at least 0.005%. When the Ti content exceeds 0.02%, precipitates may rather coarsen to cause destruction. In this case, solid solution Ti, which is not bonded with N, may remain to form Ti carbide (TiC), to deteriorate toughness of the base metal and toughness of the welded portion. Therefore, the Ti content may be in the range of 0.005 to 0.02%. More preferably, Ti may have a range of 0.005 to 0.017% to prevent coarsening of nitride.

Copper (Cu): 0.35% or less (excluding 0)

**[0022]** Cu may be an element that does not significantly deteriorate impact properties, and improves strength by solid solution and precipitation. When the Cu content exceeds 0.35%, surface cracking of the steel plate due to thermal shock may occur. Therefore, the Cu content may be in the range of 0.35% or less.

Nickel (Ni): 0.05-0.8%

**[0023]** Ni may be an element that may improve strength and toughness at the same time, although an effect of increasing strength is not great. Ni may be added in an amount of 0.05% or more in order to sufficiently obtain the effect. Since Ni is a relatively expensive element, when the Ni content exceeds 0.8%, economic efficiency may be reduced. Therefore, the Ni content may have a range of 0.05 to 0.8%. Ni has more preferably a range of 0.2 to 0.8% in a viewpoint of an increase in strength and toughness.

Niobium (Nb): 0.003-0.03%

**[0024]** Nb may be an element staying in a solid solution state or precipitating carbonitrides, suppressing recrystallization during rolling or cooling, reducing a grain size of a microstructure, and increasing strength. For the above effect, the Nb may be added in an amount of at least 0.003%. When the Nb content exceeds 0.03%, C concentration may occur due to C affinity, to promote the formation of MA phase, and to deteriorate the toughness and fracture properties at low temperatures. Therefore, the Nb content may be in the range of 0.003-0.03%.

Nitrogen (N): 0.002-0.008%

**[0025]** N, together with C, may be a main element causing strain aging, and is desirable to keep it as low as possible. In order to reduce deterioration of strain aging impact properties due to N, it is necessary to appropriately include Al, Ti, Nb, etc. When the N content is too high, since it is difficult to suppress the effect of strain aging, the N content may be

included in the range of 0.008% or less. When the N content exceeds 0.002%, toughness of the base metal and toughness of the welded portion may be deteriorated by causing solid solution strengthening or forming other precipitates in a state in which elements for suppressing the strain aging impact properties are added. Therefore, the N content may be in the range of 0.002 to 0.008%.

Calcium (Ca): 0.0002-0.0050%

**[0026]** When Ca is added to molten steel during a steelmaking process after Al deoxidation, Ca may be bonded to S which exists mainly as MnS to inhibit production of MnS, simultaneously with formation of globular-shaped CaS, to have an effect of suppressing cracks in a central portion of the steel material. Therefore, in order to form S which is added in the present disclosure into CaS sufficiently, 0.0002% or more may be added. When the Ca content is more than 0.0050%, Ca remaining after forming CaS is bonded to O to produce coarse oxidative inclusions, which is stretched and fractured in rolling to serve as a crack initiation point at low temperatures. Therefore, the Ca content may be in the range of 0.0002-0.0050%.

Chromium (Cr): 0.009% or less

**[0027]** Cr may be an element of forming a strong carbide, may reduce fraction of ferrite, and may promote formation of hard phases, to deteriorate impact toughness. Therefore, in the present disclosure, it is preferable to keep the Cr content as low as possible or not included, and in the present disclosure, it is preferable to manage an upper limit thereof to 0.009%.

Molybdenum (Mo): 0.0009% or less

**[0028]** Mo, in a similar manner to Cr, may be also an element for forming a strong carbide, may reduce a fraction of ferrite, and may promote formation of hard phases, to deteriorate impact toughness. Therefore, in the present disclosure, it is preferable to keep the Mo content as low as possible or not included, and in the present disclosure, it is preferable to manage an upper limit thereof to 0.0009%.

**[0029]** 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.

**[0030]** The microstructure of the thick steel plate provided by the present disclosure may include 95 area% or more of ferrite having an average grain size of 10 $\mu$ m or less. The crystal grains of the ferrite as described above may be miniaturized to improve the strain aging impact properties at low temperature. When the fraction of the ferrite is less than 95 area%, it may be difficult to secure the effect. More preferably, the fraction of ferrite is 98 area% or more. The remainder of the microstructure of the present disclosure may include at least one of cementite and MA, and the fraction thereof may be 5 area% or less, and more preferably 2 area% or less.

**[0031]** In addition, the ferrite may have a maximum grain size of 20 $\mu$ m or less. When the maximum grain size of the ferrite exceeds 20 $\mu$ m or less, it may be difficult to secure low-temperature strain aging impact properties targeted by the present disclosure.

**[0032]** The ferrite may consist of polygonal ferrite and acicular ferrite. Therefore, as described above, a hard phase that may be a starting point of the impact toughness may be minimized, and ferrite having good shock absorption may be configured as a microstructure, to secure shock and strain age shock at low temperature.

**[0033]** The thick steel plate of the present disclosure, provided as described above, may have a yield strength of 350MPa or more, a tensile strength of 450MPa or more, an impact toughness of 200J or more at -60°C, and a strain aging impact toughness of 100J or more at -60°C, and may secure excellent low-temperature strain aging impact properties, as well as high yield strength. The strain aging impact toughness means an impact energy value measured after aging treatment at 250°C for 1 hour, after a tensile strain of 5 to 10% is applied.

**[0034]** In addition, the thick steel plate of the present disclosure may have a thickness of 40mm or more. In the present disclosure, an upper limit of the thickness of the thick steel plate is not particularly limited, but may have, for example, a thickness of 100mm or less.

**[0035]** The thick steel plate of the present disclosure may be applied to the shipbuilding and offshore structural industries that require a bending process, a cold deformation process, and the like, and may contribute to have excellent strain aging impact properties to secure stability and extend a lifespan of the structure.

**[0036]** Hereinafter, a manufacturing method of the thick steel plate of this invention will be described in detail.

**[0037]** First, a steel slab having the alloy composition described above may be reheated at 1020 to 1150°C. When the reheating temperature exceeds 1150°C, grains of austenite may be coarsened to deteriorate toughness, and when

the reheating temperature is lower than 1050°C, Ti, Nb, and the like may not be sufficiently employed to cause a decrease in strength.

**[0038]** The reheated steel slab may be performed a recrystallization zone rolling operation in 5 passes or less (including 0 passes) to obtain a bar. In the present disclosure, the recrystallization zone rolling operation during a hot-rolling process is performed only to match a width of the product. For example, in the present disclosure, it is possible to minimize the recrystallization zone rolling operation and maximize a non-recrystallization zone rolling operation to achieve grain refinement. When the recrystallization zone rolling operation exceeds 5 passes, there may be a problem that the total reduction amount in the non-recrystallization zone rolling operation is reduced. Therefore, in the present disclosure, it is necessary to omit or minimize the recrystallization zone rolling operation.

**[0039]** The bar may be performed a non-recrystallization zone rolling operation at Ar<sub>3</sub> or higher and about 750°C or higher to obtain a hot-rolled steel material. When the rolling temperature is less than Ar<sub>3</sub> during the non-recrystallization zone rolling operation, a structure anisotropy may be formed due to stretching of ferrite, to have a problem of deteriorating impact toughness.

**[0040]** A reduction amount in the non-recrystallization zone rolling operation may be 90% or more (including 100%) of the sum of a reduction amount in the recrystallization zone rolling operation and the reduction amount in the non-recrystallization zone rolling operation. The recrystallization zone rolling operation may be performed in 5 passes or less (including 0 passes) as described above, the reduction amount in the non-recrystallization zone rolling operation may be performed at 90% or more, to realize grain refinement and secure excellent low temperature strain aging impact properties.

**[0041]** After the non-recrystallization zone rolling operation, cooling the hot-rolled steel material to 300 to 500°C at a cooling rate of 2 to 15°C/s, by a water-cooling process and the like, may be further included. When the cooling rate is less than 2°C/s, it may be difficult to secure the target strength. When the cooling rate exceeds 15°C/s, a relatively large amount of hard phase, such as MA, bainite, and the like, may be formed to deteriorate toughness.

**[0042]** In the present disclosure, in order to obtain a more sufficient aging shock guarantee temperature, the cooling may not be performed after the non-recrystallization zone rolling operation. In this case, the tensile strength may drop slightly.

[Mode for Invention]

**[0043]** Hereinafter, the present disclosure will be described more specifically through examples. However, the following examples should be considered in a descriptive sense only and not for purposes of limitation. The scope of the present invention is defined by the appended claims, and modifications and variations may be reasonably inferred therefrom.

(Example)

**[0044]** After preparing molten steel having the alloy composition shown in Table 1, using a continuous casting operation to produce a steel slab. The steel slab was reheated under the conditions shown in Table 2, hot-rolled, and cooled to prepare a thick steel plate. After measuring a microstructure and mechanical properties of the thick steel plate thus prepared, the results are shown in Table 3 below.

[Table 1]

Steel	Alloy Composition (wt%)													
	C	Si	Mn	P*	S*	Al	Ti	Cu	Ni	Nb	N*	Ca*	Cr	Mo
IS1*	0.078	0.203	1.47	77	17	0.023	0.012	0.25	0.63	0.012	35	16	0.008	0.0007
IS2	0.079	0.205	1.46	84	19	0.028	0.013	0.26	0.63	0.012	38	12	0.009	0.0009
IS3	0.065	0.213	1.56	75	20	0.022	0.0098	0.26	0.57	0.021	37	15	0.008	0.0008
IS4	0.072	0.168	1.51	65	21	0.018	0.01	0.25	0.67	0.018	35	14	0.008	0.0009
CS1**	0.105	0.198	1.48	84	18	0.025	0.011	0.27	0.61	0.023	41	12	0.008	0.0008
CS2	0.068	0.224	1.58	82	17	0.021	0.0099	0.26	0.51	0.019	90	16	0.009	0.0009
CS3	0.079	0.210	1.55	75	16	0.022	0.012	0.25	0.59	0.021	38	15	0.026	0.0009
CS4	0.08	0.215	1.56	83	19	0.024	0.011	0.24	0.58	0.022	37	14	0.008	0.007

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(continued)

Steel	Alloy Composition (wt%)													
	C	Si	Mn	P*	S*	Al	Ti	Cu	Ni	Nb	N*	Ca*	Cr	Mo

P\*, S\*, N\*, and Ca\* are provided in ppm units.

\*IS: Inventive Steel, \*\*CS: Comparative Steel

[Table 2]

	Steel	Reheat ing Temp. (°C)	Pass No. in Recrystalliza tion Zone Rolling Operation	Starting Temp. (°C) in Non- recrysta llization Zone Rolling Operation	End Temp. (°C) in Non- recrysta llization Zone Rolling Operation	Reduction Amount (%) in Non- recrystal lization Zone Rolling Operation	Cooling End Temp. (°C)	Cooling Rate (°C/s)
IE1***	IS1*	1107	-	835	764	100	422	6.8
IE2	IS2	1110	-	845	762	100	384	7.9
IE3	IS3	1114	2	840	758	91	446	6.3
IE4	IS4	1112	2	853	759	90	451	7.1
IE5	IS1	1123	-	849	758	100	-	-
CE1****	IS4	1123	8	851	764	50	398	6.9
CE2	CS1**	1109	-	832	755	100	368	8.6
CE3	CS2	1116	-	841	754	100	406	7.3
CE4	CS3	1118	-	852	751	100	415	6.8
CE5	CS4	1114	-	850	756	100	425	7.1
The reduction amount in the non-recrystallization zone rolling operation is a ratio relative to the sum of a reduction amount in the recrystallization zone rolling operation and the reduction amount in the non-recrystallization zone rolling operation								
*IS: Inventive Steel, **CS: Comparative Steel, ***IE: Inventive Example, ****CE: Comparative Example								

[Table 3]

	Average Grain Size ( $\mu\text{m}$ ) of Ferrite	Maximum Grain Size ( $\mu\text{m}$ ) of Ferrite	Fraction (area%) of Ferrite	Fraction (area%) of Balance	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Impact Toughness (@ -60°C, J)	Strain Aging Impact Toughness (@ -40°C, J)	Strain Aging Impact Toughness (@ -60°C, J)
IE1*	7.5	15	95.6	4.4	375	645	34	268	205	164
IE2	8.8	18	96.2	3.8	379	656	34	245	221	184
IE3	9.1	16	95.7	4.3	384	586	35	210	186	121
IE4	8.4	14	96.1	3.9	388	574	36	206	148	142
IE5	9.6	18	95.7	4.3	421	522	36	312	252	202
CE1**	24	42	78.6	21.4	382	633	30	154	86	22
CE2	9.6	19	84.2	15.8	392	643	31	98	24	18
CE3	8.7	18	95.2	4.8	376	634	30	84	26	15
CE4	9.4	17	91.4	8.6	412	635	29	58	22	8
CE5	9.2	19	93.4	6.6	409	645	28	68	18	8
The balance means one or more of cementite and MA.										
*IE: Inventive Example, **CE: Comparative Example										



**[0045]** As can be seen from Tables 1 to 3, in cases of Inventive Examples 1 to 5 that satisfy the alloy composition and the manufacturing conditions proposed by the present disclosure, it can be confirmed that an average grain size of the ferrite was secured to have 10  $\mu\text{m}$  or less, and a fraction of the ferrite was secured to have 95 area%, to have a yield strength of 350MPa or more, a tensile strength of 450MPa or more, an impact toughness of 200J or more at  $-60^{\circ}\text{C}$ , and a strain aging impact toughness of 100J or more at  $-60^{\circ}\text{C}$ . In cases of Comparative Examples 1 to 3 that do not satisfy the alloy composition or the manufacturing conditions of the present disclosure, it can be seen that the desired strain aging impact toughness of the present disclosure was not secured.

**[0046]** In cases of Inventive Examples 1 and 2 satisfied the alloy composition, not performed a recrystallization zone rolling operation, and only performed a non-recrystallization zone rolling operation, it can be seen that fine microstructure and excellent mechanical properties were secured.

**[0047]** In cases of Inventive Examples 3 and 4 satisfied the alloy composition, performed a recrystallization zone rolling operation in two passes for width control of the product, and performed a non-recrystallization zone rolling operation, it can be seen that fine microstructure and excellent mechanical properties were secured.

**[0048]** In a case of Inventive Example 5 satisfied the alloy composition, performed a recrystallization zone rolling operation, and not performed a water cooling operation, it can be seen to have a slightly lower strength, but excellent strain aging impact properties, relative to a case in which the water cooling operation was performed.

**[0049]** In a case of Comparative Example 1 satisfied the alloy composition of the present disclosure, performed a recrystallization zone rolling operation in 8 passes, and applied a conventional TMCP process. In the case of Comparative Example 1, it can be seen that the low-temperature strain aging impact toughness is low due to the coarsening of ferrite grains.

**[0050]** In cases of Comparative Examples 2 and 3, respectively, in which the C and N contents exceed the conditions of the present disclosure, it can be seen that the low-temperature strain aging impact toughness is relatively low, and it is believed that the interstitial elements C and N were fixed to the dislocation to deteriorated toughness. In particular, in the case of Comparative Example 2, it can be seen that impact toughness was deteriorated due to an increase in pearlite by over-addition of C.

**[0051]** In cases of Comparative Examples 4 and 5, respectively, the Cr and Mo contents exceed the conditions of the present disclosure, although they satisfy the manufacturing conditions of the present disclosure, it can be seen that the low-temperature strain aging impact toughness is relatively low. This is believed to be due to a decrease in ferrite fraction and an increase in hard phase under the influence of strong carbide forming elements, Mo and Cr.

**[0052]** FIG. 1 is a captured photograph of a microstructure of Inventive Example 1. As can be seen in FIG. 1, in the case of Inventive Example 1 that satisfies the conditions of the present disclosure, it can be confirmed that grains of the microstructure were fine.

**[0053]** FIG. 2 is a captured photograph a microstructure of Comparative Example 1. As can be seen in FIG. 2, in the case of Comparative Example 1 that does not satisfy the conditions of the present disclosure, it can be confirmed that grains of the microstructure were coarse.

## Claims

1. A thick steel plate having excellent low-temperature strain aging impact properties, comprising, by weight, C: 0.04 to 0.1%, Si: 0.05 to 0.4%, Mn: 1.0 to 2.0%, P: 0.01% or less, S: 0.003% or less, Al: 0.015 to 0.04%, Ti: 0.005 to 0.02%, Cu: 0.35% or less (excluding 0), Ni: 0.05 to 0.8%, Nb: 0.003 to 0.03%, N: 0.002 to 0.008%, Ca: 0.0002 to 0.0050%, Cr: 0.009% or less, Mo: 0.0009% or less, a balance of Fe and other inevitable impurities, and comprising 95 area% or more of ferrite having an average grain size of 10 $\mu\text{m}$  or less as a microstructure.
2. The thick steel plate of claim 1, wherein the ferrite consists of polygonal ferrite and acicular ferrite.
3. The thick steel plate of claim 1, wherein the ferrite has a maximum grain size of 20 $\mu\text{m}$  or less.
4. The thick steel plate of claim 1, wherein the microstructure comprises 5 area% or less of one or more of cementite and a martensite-austenite (MA).
5. The thick steel plate of claim 1, wherein the thick steel plate has a thickness of 40mm or more.
6. The thick steel plate of claim 1, wherein the thick steel plate has a yield strength of 350MPa or more, a tensile strength of 450MPa or more, an impact toughness of 200J or more at  $-60^{\circ}\text{C}$ , and a strain aging impact toughness of 100J or more at  $-60^{\circ}\text{C}$ .

7. A method of manufacturing a thick steel plate having excellent low-temperature strain aging impact properties, comprising:

reheating a steel slab including, by weight, C: 0.04 to 0.1%, Si: 0.05 to 0.4%, Mn: 1.0 to 2.0%, P: 0.01% or less, S: 0.003% or less, Al: 0.015 to 0.04%, Ti: 0.005 to 0.02%, Cu: 0.35% or less (excluding 0), Ni: 0.05 to 0.8%, Nb: 0.003 to 0.03%, N: 0.002 to 0.008%, Ca: 0.0002 to 0.0050%, Cr: 0.009% or less, Mo: 0.0009% or less, a balance of Fe and other inevitable impurities, at 1020 to 1150°C;

performing a recrystallization zone rolling operation of the reheated steel slab in 5 passes or less (including 0 passes) to obtain a bar; and

performing a non-recrystallization zone rolling operation on the bar at Ar<sub>3</sub> or higher to obtain a hot-rolled steel material.

8. The method of claim 7, wherein a reduction amount in the non-recrystallization zone rolling operation is 90% or more (including 100%) of the sum of a reduction amount in the recrystallization zone rolling operation and the reduction amount in the non-recrystallization zone rolling operation.

9. The method of claim 7, further comprising cooling the hot-rolled steel material to 300 to 500°C at a cooling rate of 2 to 15°C/s, after the non-recrystallization zone rolling operation.

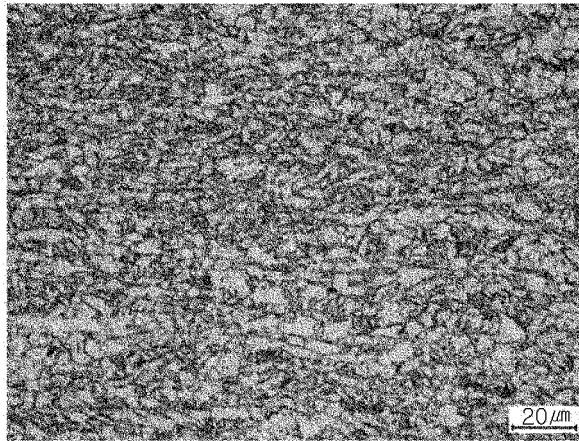


FIG. 1

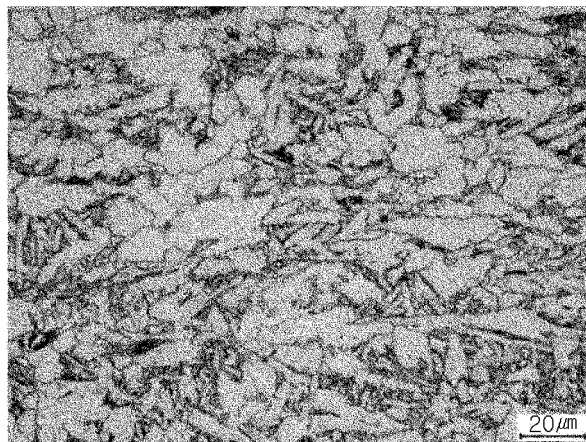


FIG. 2

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2018/011722

## A. CLASSIFICATION OF SUBJECT MATTER

C21D 8/02(2006.01)i, C22C 38/02(2006.01)i, C22C 38/04(2006.01)i, C22C 38/14(2006.01)i, C22C 38/16(2006.01)i, C22C 38/08(2006.01)i, C22C 38/58(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)

C21D 8/02; B21B 3/00; C22C 38/00; C22C 38/14; C22C 38/16; C22C 38/02; C22C 38/04; C22C 38/08; C22C 38/58

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: toughness, fall, prevention, rear plate, re-heating, rolling, Ar3, pass number

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2012-229470 A (KOBE STEEL LTD.) 22 November 2012 See paragraphs [0001], [0110]; and claims 1-3.	1-9
Y	KR 10-2017-0075851 A (POSCO) 04 July 2017 See paragraphs [0006]-[0007], [0066]-[0072]; and claims 1-6.	1-9
A	KR 10-2008-0040233 A (POSCO) 08 May 2008 See paragraphs [0007], [0080]-[0089]; and claims 1-7.	1-9
A	KR 10-2009-0070485 A (POSCO) 01 July 2009 See paragraphs [0053]-[0080]; and claims 1-3.	1-9
A	KR 10-2011-0130974 A (HYUNDAI STEEL COMPANY) 06 December 2011 See paragraphs [0044]-[0061]; and claims 1-5.	1-9

☐ 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

“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

10 JANUARY 2019 (10.01.2019)

Date of mailing of the international search report

10 JANUARY 2019 (10.01.2019)

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**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

International application No.

**PCT/KR2018/011722**

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**REFERENCES CITED IN THE DESCRIPTION**

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**Non-patent literature cited in the description**

- **VK HEIKKINEN ; JD BOYD.** The effect of processing variables on the mechanical properties and strain ageing of high-strength low-alloy V and VN steels. *CANADIAN METALLURGICAL QUARTERLY*, 1976, vol. 15 (3), 219 **[0008]**