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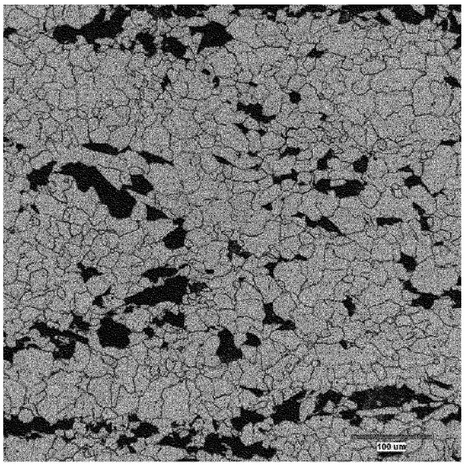
(54) ULTRATHICK STEEL PLATE HAVING EXCELLENT LOW-TEMPERATURE IMPACT TOUGHNESS AND METHOD FOR MANUFACTURING SAME

(57) The present invention relates to structural steel which can be used, for example, as materials for marine, bridge, and building applications and, more specifically, to an ultrathick steel plate having excellent low-temperature impact toughness and a method for manufacturing same.

[FIG.1]



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Description

Technical Field

[0001] The present disclosure relates to structural steel materials which can be used, for example, as a material for marine, bridge, and construction and, more specifically, to an ultra-thick steel plate having excellent low-temperature impact toughness and a method for manufacturing the same.

Background Art

[0002] An ultra-thick steel plate having a certain thickness or more may be manufactured through a thick plate process, and in this case, a rolling method may be divided into general rolling, normalizing rolling, and thermo-mechanical controlled rolling (TMCP), and the like. In addition, a heat treatment process may be performed after rolling, and in this case, the heat treatment process includes a normalizing heat treatment process, a quenching heat treatment process, a quenching-tempering heat treatment, and the like.

[0003] Among the above-described rolling processes, general rolling is a method of rolling without controlling a rolling temperature, which may be mainly applied to general steel not requiring impact toughness.

[0004] Unlike this, TMCP performs recrystallization region rolling and non-recrystallization region rolling through temperature control, and it is possible to secure strength and impact toughness through cooling, as necessary. However, when an ultra-thick material is manufactured through such a TMCP process, a long waiting time is required to adjust a rolling temperature, resulting in a serious decrease in productivity.

[0005] Normalizing rolling is finished at a relatively high temperature, so strength and toughness may decrease due to grain growth during air cooling.

[0006] Therefore, when manufacturing an ultra-thick steel plate through a TMCP process, a normalizing rolling process, or a heat treatment process after rolling, a high carbon component system containing 0.12% or more of C is required to be applied to secure strength, but due to severe deterioration in toughness, impact toughness may be guaranteed at room temperature and 0°C, and there is a problem in that a cost due to a heat treatment increases.

[0007] Meanwhile, the ultra-thick steel plate may be applied to various structural industries such as infrastructure industries such as ships, and various frames of offshore structures, bridges, construction, and the like, and wind power substructures, and the like.

[0008] Recently, in most fields such as infrastructure industries, energy industries, and the like, there has been a tendency for structures to be larger, due to minimization of installation costs and deterioration of installation environments, and it is expected that, among structural steel plates used in various industrial fields, demand for an ultra-thick steel plate having a thickness of 100 mm or more will increase in line with the tendency for structures to be larger.

[0009] However, a metallurgical disadvantage of ultra-thick steel plates is that it is difficult to realize strength and secure toughness due to a decrease in a rolling amount and limitations in a cooling process.

[0010] Due to the limitations of the rolling and cooling processes when manufacturing such ultra-thick steel plates, there is a tendency to excessively add alloy components to realize the strength of the steel plates, which may cause a problem of cost increase as well as a rapidly inferior toughness of the steel plates.

[0011] In addition, in the case of removing alloy components adversely affecting toughness in order to secure the toughness of the ultra-thick steel plate, causing a decrease in strength.

[0012] Therefore, the development of a technology that can achieve both the strength and toughness of the ultra-thick steel plate is required.

[0013] (Patent Document 1) Korean Patent Publication No. 10-2014-0003010

Summary of Invention

Technical Problem

[0014] An aspect of the present disclosure is to provide an ultra-thick steel plate having excellent strength and low-temperature impact toughness by overcoming metallurgical disadvantages of the existing ultra-thick steel plate and a method for manufacturing the same.

[0015] An object of the present disclosure is not limited to the above description. The object of the present disclosure will be understood from the entire content of the present specification, and a person skilled in the art to which the present disclosure pertains will understand an additional object of the present disclosure without difficulty.

Solution to Problem

[0016] According to an aspect of the present disclosure, provided is an ultra-thick steel plate having excellent low-temperature impact toughness, the ultra-thick steel plate including, by weight: 0.06 to 0.1% of carbon (C), 0.3 to 0.5% of silicon (Si), 1.35 to 1.65% of manganese (Mn), 0.015 to 0.04% of aluminum (sol.Al), 0.015 to 0.04% of niobium (Nb), 0.005 to 0.02% of titanium (Ti), 0.15 to 0.4% of chromium (Cr), 0.3 to 0.5% of nickel (Ni), 0.002 to 0.008% of nitrogen (N), 0.01% or less (excluding 0%) of phosphorus (P), 0.003% or less (excluding 0%) of sulfur (S), with a balance of iron (Fe) and inevitable impurities, satisfying the following Relational Expression 1,

[0017] wherein the ultra-thick steel plate includes, by area fraction: 80 to 90% of ferrite and a remainder of pearlite as a microstructure.

[Relational Expression 1]

$$Mn + 5(Ni+Cr) \geq 3.6$$

where, each element refers to a weight content.

[0018] According to another aspect of the present disclosure, provided is a method for manufacturing an ultra-thick steel plate having excellent low-temperature impact toughness, the method including operations of: preparing a steel slab satisfying the above-described alloy composition and Relational Expression 1; heating the steel slab at a temperature within a range of 1020 to 1150°C; subjecting the heated steel slab to rough rolling at 1000°C or higher; finish hot rolling the steel slab at a temperature directly above a no-recrystallization temperature (Tnr) or at a temperature within a range of Tnr to A3 after the rough rolling; and air cooling the same after the finish hot rolling.

Advantageous Effects of Invention

[0019] As set forth above, according to the present disclosure, an ultra-thick steel plate having excellent strength and low-temperature impact toughness for an ultra-thick steel plate having a thickness of 100 to 200 mm may be provided.

[0020] As a structural material, the ultra-thick steel plate of the present disclosure may be used in various fields, such as infrastructure industries such as ships, various frames of marine structures, bridges, construction, and the like, and wind power substructures, and the like.

Brief description of the Drawings

[0021] FIG. 1 illustrates a photograph of a microstructure of an ultra-thick steel plate according to an embodiment of the present disclosure.

Best Mode for Invention

[0022] In providing an ultra-thick steel plate having a thickness of 100 mm or more (100 to 200 mm) suitable for a structural steel material, the inventors of the present disclosure have studied in depth a method for securing excellent strength and low-temperature impact toughness.

[0023] As a result thereof, it was confirmed that the ultra-thick steel plate having target physical properties can be provided by optimizing an alloy composition system of the ultra-thick steel plate and a rolling process, and thus the present disclosure was provided.

[0024] In particular, the present disclosure has technical significance in that it is possible to solve a problem of productivity of the existing TMCP steel material, a problem of securing physical properties of a general rolling material and heat treatment material, a problem of heat treatment material costs, and the like.

[0025] Hereinafter, the present disclosure will be described in detail.

[0026] According to an aspect of the present disclosure, an ultra-thick steel plate having excellent low-temperature impact toughness may include, by weight: 0.06 to 0.1% of carbon (C), 0.3 to 0.5% of silicon (Si), 1.35 to 1.65% of manganese (Mn), 0.015 to 0.04% of aluminum (sol.Al), 0.015 to 0.04% of niobium (Nb), 0.005 to 0.02% of titanium (Ti), 0.15 to 0.4% of chromium (Cr), 0.3 to 0.5% of nickel (Ni), 0.002 to 0.008% of nitrogen (N), 0.01% or less (excluding 0%) of phosphorus (P), 0.003% or less (excluding 0%) of sulfur (S).

[0027] Hereinafter, a reason for limiting the alloy composition of the steel sheet provided in the present disclosure as above will be described in detail.

[0028] Meanwhile, in the present disclosure, unless otherwise specified, a content of each element is based on weight, and a ratio of structure is based on area.

Carbon (C): 0.06 to 0.1%

[0029] Carbon (C) is an element causing solid solution strengthening and combining with Nb, and the like in steel to form carbonitrides, which is advantageous for securing strength of steel.

[0030] In order to sufficiently obtain the strength effect of C, C may be included in an amount of 0.06% or more, but when the C content exceeds 0.1%, a pearlite phase is excessively formed as a microstructure, so that there is a problem impact and fatigue properties at a low temperature deteriorates. In addition, as a content of solid solution C increases, the impact properties decrease.

[0031] Therefore, the C may be included in an amount of 0.06 to 0.1%, and more advantageously, in an amount of 0.07% or more and 0.09% or less.

Silicon (Si): 0.3 to 0.5%

[0032] Silicon (Si) serves to deoxidize molten steel together with aluminum (Al). Si has an effect on improving strength, but when the Si content is excessive, impact and fatigue properties at a low temperature may be impaired, so that it is necessary to add Si in an appropriate amount.

[0033] When the Si content is less than 0.3%, sufficient strength cannot be secured, and on the other hand, when the Si content exceeds 0.5%, diffusion of C is hindered so that there is a problem in that formation of a MA phase (martensite-austenite mixed structure) is promoted.

[0034] Accordingly, Si may be included in an amount of 0.3 to 0.5%.

Manganese (Mn): 1.35 to 1.65%

[0035] Manganese (Mn) is an element having a great effect on improving strength by solid solution strengthening, and may be included in an amount of 1.35% or more. However, when the Mn content is excessive, since there is a concern that toughness may be deteriorated due to formation of MnS inclusions and center portion segregation, Mn may be included in an amount of 1.65% or less in consideration thereof.

Aluminum (Sol.Al): 0.015 to 0.04%

[0036] Aluminum (Sol.Al) is a major deoxidizer of steel, and is advantageous for fixing nitrogen (N) in steel. To this end, it is advantageous to include Al in an amount of 0.015% or more, but when the Al content exceeds 0.04%, a fraction and size of Al_2O_3 inclusions increase, which causes low-temperature toughness to be impaired. In addition, similar to Si, there is a problem in that low-temperature toughness and low-temperature fatigue properties are deteriorated by accelerating the formation of the MA phase in a base material and a weld heat-affected zone.

[0037] Therefore, Al may be included in an amount of 0.015 to 0.04%.

Niobium (Nb) : 0.015 to 0.04%

[0038] Niobium (Nb) has a solid solution strengthening effect, and is advantageous in improving strength by suppressing recrystallization during rolling or cooling by forming a carbonitride to finely form a structure.

[0039] In order to sufficiently obtain the above effects, Nb may be contained in an amount of 0.015% or more. On the other hand, when the content of Nb is excessive, C concentration occurs due to C affinity, so that the formation of the MA phase is promoted and there is a problem of impairing toughness and fatigue properties at a low temperature, so that the content of Nb may be limited to be 0.04% or less in consideration thereof.

[0040] Therefore, Nb may be included in an amount of 0.015 to 0.04%, more advantageously, Nb may be included in an amount of 0.02% or more.

Titanium (Ti): 0.005 to 0.02%

[0041] Titanium (Ti) combines with nitrogen (N), which may deteriorate impact properties and surface quality of steel, to form a Ti-based nitride (TiN), and serves to reduce a content of dissolved N. The Ti-based precipitate contributes to refinement by suppressing coarsening of a structure, and is useful for improving toughness.

[0042] In order to sufficiently obtain the above-described effect, Ti may be contained in an amount of 0.005% or more, but when the Ti content exceeds 0.02%, causing destruction due to coarsening of precipitates, and dissolved Ti remaining after combining with N forms a Ti-based carbide (TiC), so that there is a problem of impairing toughness a base material and a weld zone.

[0043] Therefore, Ti may be included in an amount of 0.005 to 0.02%, and more advantageously, Ti may be included in an amount of 0.01% or more.

Chromium (Cr): 0.15 to 0.4%

[0044] Chromium (Cr) is an element advantageous for improving strength by increasing hardenability of steel.
[0045] In order to sufficiently obtain the above-described effect, Cr may be included in an amount of 0.15% or more, but when a content of Cr exceeds 0.4%, not only weldability is deteriorated, but also there is a problem of causing an increase in manufacturing costs as an expensive element.
[0046] Accordingly, Cr may be included in an amount of 0.15 to 0.4%.

Nickel (Ni): 0.3 to 0.5%

[0047] Nickel (Ni) is an element that can simultaneously improve strength and toughness of steel.
[0048] In particular, in order to sufficiently obtain an effect of improving strength and toughness in the rolling process according to the present disclosure, Ni may be contained in an amount of 0.3% or more. However, when the Ni content exceeds 0.5%, the above-described effect is saturated, but there is a problem in that manufacturing cost increases.
[0049] Therefore, Ni may be included in an amount of 0.3 to 0.5%.

Nitrogen (N): 0.002 to 0.008%

[0050] Nitrogen (N) combines with Ti, Nb, Al, and the like in steel to form precipitates, and these precipitates are effective in improving strength and toughness by forming a fine austenite structure during reheating.
[0051] In order to sufficiently obtain the above-described effect, it is advantageous to add 0.002% or more of N, but when the N content exceeds 0.008%, surface cracks are caused at a high temperature, and N remaining after forming precipitates exists in an atomic state, causing toughness of steel to be impaired.
[0052] Therefore, N may be included in an amount of 0.002 to 0.008%.

Phosphorus (P): 0.01% or less (excluding 0%)

[0053] Phosphorus (P) is an element which causes grain boundary segregation, which may cause brittleness of steel. Therefore, the content of P should be controlled to be as low as possible.
[0054] In the present disclosure, even when the P is contained in a maximum amount of 0.01%, there is no problem in securing intended physical properties, so that the P content may be limited to be 0.01% or less. However, 0% may be excluded, considering an inevitably added level.

Sulfur (S): 0.003% or less (excluding 0%)

[0055] Sulfur (S) mainly combines with Mn in steel, to form MnS inclusions, which is a factor impairing low-temperature toughness.
[0056] Therefore, in order to secure the low-temperature toughness and low-temperature fatigue characteristics targeted in the present disclosure, the S content should be controlled to be as low as possible, and may be preferably limited to be 0.003% or less. However, 0% may be excluded, considering an inevitably added level.
[0057] 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.
[0058] It is preferable that in the steel plate of the present disclosure satisfying the above-described alloy composition, a relationship between Mn, Ni, and Cr in steel satisfies the following Relational Expression 1.

[Relational Expression 1]

$$Mn + 5(Ni+Cr) \geq 3.6$$

where, each element refers to a weight content.
[0059] In the present disclosure, in order to improve low-temperature toughness of an ultra-thick steel plate having a thickness of 100 to 200 mm, the content of C may be limited to be 0.10% or less. In the present disclosure, the relationship between Mn, Ni, and Cr in steel is controlled by the Relational Expression 1, so that it is not adversely affected to secure

strength, even when the C content is relatively lowered.

[0060] Specifically, when the content relationship between Mn, Ni, and Cr in the alloy composition proposed in the present disclosure does not satisfy the above Relational Expression 1, that is, when a value of Relational Expression 1 is less than 3.6, the strength of the ultra-thick steel plate having a maximum thickness of 200mm may not be obtained.

[0061] The ultra-thick steel plate of the present disclosure satisfying the above-described alloy composition and Relational Expression 1 may have a microstructure composed of a composite structure of ferrite and pearlite.

[0062] Specifically, it is preferable that the ultra-thick steel plate of the present disclosure includes, by area fraction: 80 to 90% of ferrite, and a remainder of pearlite.

[0063] When the fraction of the ferrite is less than 80%, it is difficult to secure low-temperature toughness of the ultra-thick steel plate. On the other hand, when the fraction of the ferrite exceeds 90%, the fraction of pearlite is insufficient, making it impossible to secure the target level of strength.

[0064] In addition, the ultra-thick steel plate of the present disclosure has a fine structure as an average grain size of the ferrite is 50 μm or less.

[0065] Here, it should be noted that the average grain size is based on a circle equivalent diameter.

[0066] As described above, the present disclosure has an effect capable of securing excellent strength and low-temperature toughness at the same time, by finely implementing the structure of the ultra-thick steel plate.

[0067] Specifically, the ultra-thick steel plate of the present disclosure may have a yield strength of 300 MPa or more and an impact toughness of 200 J or more at -20°C, showing high strength and excellent low-temperature impact toughness.

[0068] Hereinafter, a method for manufacturing an ultra-thick steel plate having excellent low-temperature impact toughness according to another aspect of the present disclosure will be described in detail.

[0069] In brief, the steel plate may be manufactured by preparing a steel slab satisfying the alloy composition and Relational Expression 1 proposed in the present disclosure, then subjecting the steel slab to the processes of [heating - rolling - air cooling]. In particular, in the present disclosure, there is technical significance in that a rolling process is performed in a normalizing heat-treatment region as a rolling process without performing a separate heat treatment after completing the rolling process.

[0070] Each process condition will be described in detail below.

[Steel slab heating]

[0071] In the present disclosure, it is preferable to perform a process of heating and homogenizing a steel slab prior to performing a rolling process, and in this case, a heating process may be performed in a temperature range of 1020 to 1150°C.

[0072] When a heating temperature of the steel slab is lower than 1020°C, Ti, Nb, and the like, may not be sufficiently dissolved, resulting in a decrease in strength. On the other hand, when the heating temperature thereof is higher than 1150°C, grains of austenite are coarsened, so that there is a concern that toughness of steel may be deteriorated.

[0073] The steel slab may have a thickness of 400 mm or less to secure a sufficient amount of rolling to secure strength and toughness, while having a maximum thickness of 200 mm by a subsequent rolling process.

[Rolling process]

[0074] A hot-rolled steel sheet may be manufactured by hot rolling the steel slab heated according to the above.

[0075] In the present disclosure, the hot rolling is preferably performed in an operation of [recrystallization region rolling (rough rolling) - non-recrystallization region rolling (finish rolling)].

[0076] The rough rolling may be performed at 1000°C or higher, so that austenite may be completely recrystallized.

[0077] Thereafter, finish rolling may be performed in an austenite single phase region at a temperature directly above a no-recrystallization temperature (Tnr) or at a temperature within a range of Tnr to A3. In this case, it is advantageous to perform finish rolling close to the A3 temperature , in order to further promote the grain refinement effect, but it is advantageous to perform the finish rolling directly above the Tnr temperature in order to obtain the normalizing effect. The temperature directly above the Tnr may be expressed as a temperature range of greater than Tnr to Tnr+50°C.

[0078] The Tnr and A3 temperatures may be obtained by the following formulas, where each element means a weight content.

$$Tnr = 887 + 464C + (6445Nb - 644\sqrt{Nb}) + (732V - 230\sqrt{V}) + 890Ti + 363Al - 357Si$$

$$A3 = 910 - 203\sqrt{C} - 15.2Ni + 44.7Si + 104V + 31.5Mo - 30Mn + 11Cr + 20Cu - 700P - 400Al - 400Ti$$

[0079] When a temperature during the finish rolling is lower than A3, two-phase region rolling is performed, and a normalizing effect is insufficient, so that there may be a concern that an additional heat-treatment process is required.
[0080] More preferably, the finish rolling may be completed in a temperature range of 820 to 900°C.
[0081] Since the present disclosure intends to obtain an ultra-thick steel plate having a maximum thickness of 200 mm by performing the above-described rolling process, it is necessary to consider distribution of a reduction ratio during rough rolling and finish rolling in the rolling process.
[0082] In the present disclosure, it is preferable that a residual rolling reduction immediately after the rough rolling is controlled to be 25 to 35%. When the residual rolling reduction is less than 25%, there is a problem that a rough rolling process is prolonged and productivity is lowered. On the other hand, when the residual rolling reduction ratio exceeds 35%, there is a concern that sound rolling may not be achieved due to generation of a load on a rolling mill during finish rolling after rough rolling.
[0083] Here, it should be noted that the residual rolling reduction refers to an amount of finish rolling remaining to the target thickness after rough rolling.

[Air cooling]

[0084] Cooling may be performed on a hot-rolled steel sheet obtained by completing the rolling process according to the above, and in this case, it is preferable to perform air cooling in order to realize a normalizing effect.
[0085] By performing air cooling after completing the rolling process according to the present disclosure, not only an effect of grain refinement may be achieved, but also an effect of obtaining an ultra-thick steel plate having excellent strength and toughness without performing a subsequent heat treatment process.
[0086] More specifically, as the intended microstructure is formed, in the ultra-thick steel plate of the present disclosure, both excellent strength and toughness characteristics may be secured for ultra-thick steel having a thickness of 100 to 200 mm.
[0087] In order to secure strength, a steel plate manufactured by a conventional normalizing heat treatment has a carbon content higher than that of a TMCP steel material manufactured by control rolling + cooling, so that the steel material manufactured by the conventional normalizing heat treatment tends to have inferior impact toughness even after a heat treatment. In addition, when the heat treatment temperature is too high, or a time for the heat treatment is too long, the strength compared to the steel plate in a rolled state before the heat treatment may decrease due to grain growth.
[0088] In the case of manufacturing an ultra-thick steel plate by the TMCP process, since an air-cooling waiting time of several minutes is required due to temperature control, productivity is lowered and costs due to water treatment are required, which is economically disadvantageous.
[0089] The present disclosure proposes a manufacturing method capable of overcoming the disadvantages of the ultra-thick plate produced by the above-described process, and by optimizing rolling and cooling conditions for a slab having a specific alloy component system, an ultra-thick plate having excellent strength and low-temperature toughness characteristics may be provided.
[0090] Hereinafter, the present disclosure will be described in more detail through the following Examples. However, it should be noted that the following Examples are only for describing the present disclosure in detail by illustration, and are not intended to limit the right scope of the present disclosure. The reason is that the right scope of the present disclosure is determined by the matters described in the claims and reasonably inferred therefrom.

Mode for Invention

(Example)

[0091] A steel slab having alloy compositions shown in Table 1 was prepared. In this case, a content of the alloy compositions is weight %, and a remainder thereof includes Fe and inevitable impurities.
[0092] The prepared steel slab was subjected to heating, hot rolling (rough rolling and finish rolling), and cooling (air cooling) under the conditions shown in Table 2, so that each hot-rolled steel plate was manufactured. In this case, rough rolling was performed at 1000°C or higher.

[Table 1]

Steel type	Alloy composition (weight %)											Relational Expression 1
	C	Si	Mn	P	S*	Sol.Al	Cr	Ni	Ti	Nb	N	
A	0.079	0.43	1.54	0.007	<0.002	0.023	0.247	0.364	0.012	0.029	0.0034	4.595
B	0.077	0.38	1.53	0.005	<0.002	0.028	0.261	0.378	0.011	0.027	0.0038	4.725
C	0.082	0.40	1.56	0.005	<0.002	0.025	0.246	0.410	0.013	0.031	0.0033	4.84
D	0.153	0.44	1.53	0.006	<0.002	0.022	0.245	0.384	0.013	0.027	0.0040	4.675
E	0.083	0.38	1.44	0.007	<0.002	0.025	0.137	0.243	0.013	0.024	0.0036	3.34

S*: a content of S* is less than 0.002% in all steel types

[Table 2]

Test No.	Steel type	Heating temperature (°C)	Finish rolling			Division
			Start temperature (°C)	End temperature (°C)	Residual rolling reduction (%)	
1	A	1148	912	890	28	Inventive Example 1
2	B	1135	899	872	27	Inventive Example 2
3	C	1145	851	831	30	Inventive Example 3
4	A	1143	966	942	28	Comparative Example 1
5	D	1138	903	888	27	Comparative Example 2
6	E	1140	873	852	29	Comparative Example 3

[0093] A microstructure and mechanical properties of each hot-rolled steel plate manufactured as above were measured, and the results thereof were shown in Table 3.

[0094] In the microstructure of each hot-rolled steel platet, a specimen collected at 1/4t point was observed with an optical microscope (OM), where t means a thickness (mm), and a Charpy impact test was performed on the same specimen at -20°C to evaluate impact toughness.

[0095] In addition, a tensile strength, a yield strength, and an elongation were measured using a universal tensile tester for the specimens collected in accordance with the JIS No. 5 standard.

[Table 3]

Division	Thick ness (mm)	Microstructure			Mechanical properties			
		F* fraction (%)	F size* (μm)	P* fraction (%)	Yield strength (MPa)	Tensile strength (MPa)	Elonga tion (%)	Impact toughness (J. -20°C)
Inventive Example 1	200	87	45	13	361	486	34	298
Inventive Example 2	200	85	38	15	323	458	32	275
Inventive Example 3	200	83	42	17	343	467	30	230
Comparative Example 1	200	78	77	22	295	423	39	36
Comparative Example 2	200	72	44	28	356	481	29	21
Comparative Example 3	200	84	40	16	287	396	38	223
F*: Ferrite, P*: Pearlite F size* means an average grain size based on a circle equivalent diameter								

[0096] As shown in Tables 1 to 3, in Inventive Examples 1 to 3 satisfying all of the alloy composition, Relational Expression 1, and manufacturing conditions proposed in the present disclosure, it can be confirmed the steel plates have a yield strength of 300 MPa or more, and an impact toughness of 200 J or more at -20°C, which has high strength and excellent low-temperature impact toughness.

[0097] On the other hand, in the case of Comparative Example 1, satisfying the alloy composition system proposed in the present disclosure but having an excessively high end temperature during finish rolling, coarse ferrite was formed, resulting in inferior strength and toughness.

[0098] In addition, in Comparative Example 2, in which a C content in the steel was excessive, pearlite was excessively formed, and strength was secured, but toughness was greatly inferior.

[0099] In Comparative Example 3, deviating from the Relational Expression 1 proposed in the present disclosure, it can be confirmed that the strength is reduced even though a microstructure is formed as desired in the present disclosure. This proves that it is difficult to secure the target strength when a content of hardenable elements in steel is not optimized according to the Relational Expression 1 of the present disclosure.

[0100] FIG. 1 is a photograph of the microstructure of Inventive Example 3, and it can be confirmed that a composite structure with pearlite is formed with a fine ferrite phase as a main phase.

[0101] 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. An ultra-thick steel plate having excellent low-temperature impact toughness, comprising, by weight: 0.06 to 0.1% of carbon (C), 0.3 to 0.5% of silicon (Si), 1.35 to 1.65% of manganese (Mn), 0.015 to 0.04% of aluminum (sol.Al), 0.015 to 0.04% of niobium (Nb), 0.005 to 0.02% of titanium (Ti), 0.15 to 0.4% of chromium (Cr), 0.3 to 0.5% of nickel (Ni), 0.002 to 0.008% of nitrogen (N), 0.01% or less (excluding 0%) of phosphorus (P), 0.003% or less (excluding 0%) of sulfur (S), with a balance of iron (Fe) and inevitable impurities, satisfying the following Relational Expression 1, wherein the ultra-thick steel plate includes, by area fraction: 80 to 90% of ferrite and a remainder of pearlite as a microstructure,

   [Relational Expression 1]

   $$Mn + 5(Ni+Cr) \geq 3.6$$

   where, each element refers to a weight content.

2. The ultra-thick steel plate having excellent low-temperature impact toughness of claim 1, wherein the ferrite has an average grain size of 50 μm or less.

3. The ultra-thick steel plate having excellent low-temperature impact toughness of claim 1, wherein the steel plate has a yield strength of 300 MPa or and an impact toughness of 200J or more at -20°C.

4. The ultra-thick steel plate having excellent low-temperature impact toughness of claim 1, wherein the steel plate has a thickness of 100 to 200 mm.

5. A method for manufacturing an ultra-thick steel plate having excellent low-temperature impact toughness, comprising operations of:

   preparing a steel slab including, by weight: 0.06 to 0.1% of carbon (C), 0.3 to 0.5% of silicon (Si), 1.35 to 1.65% of manganese (Mn), 0.015 to 0.04% of aluminum (sol.Al), 0.015 to 0.04% of niobium (Nb), 0.005 to 0.02% of titanium (Ti), 0.15 to 0.4% of chromium (Cr), 0.3 to 0.5% of nickel (Ni), 0.002 to 0.008% of nitrogen (N), 0.01% or less (excluding 0%) of phosphorus (P), 0.003% or less (excluding 0%) of sulfur (S), with a balance of iron (Fe) and inevitable impurities, satisfying the following Relational Expression 1,
   heating the steel slab at a temperature within a range of 1020 to 1150°C;
   subjecting the heated steel slab to rough rolling at 1000°C or higher;
   finish hot rolling the steel slab at a temperature directly above a no-recrystallization temperature (Tnr) or at a temperature within a range of Tnr to A3 after the rough rolling; and
   air cooling the same after the finish hot rolling,

[Relational Expression 1]

$$Mn + 5(Ni+Cr) \geq 3.6$$

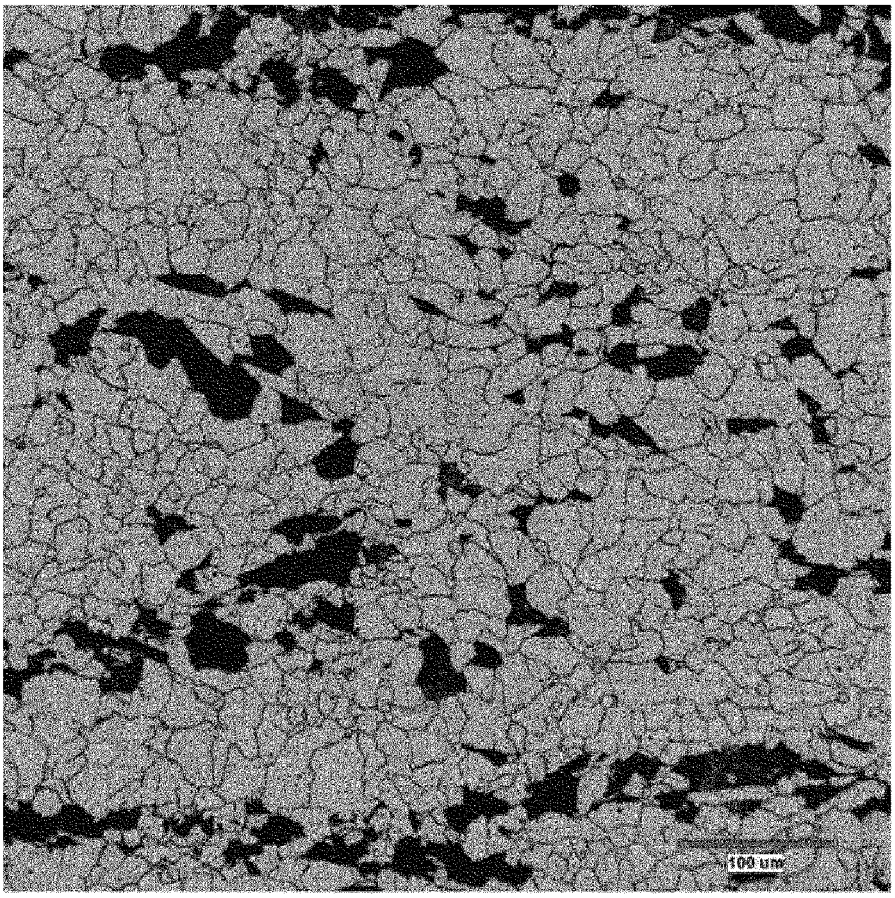
where, each element refers to a weight content.

6. The method of claim 5, wherein the finish hot rolling ends in a temperature range of 820 to 900°C.

7. The method of claim 5, wherein a residual rolling reduction after the rough rolling is 25 to 35%.

8. The method of claim 5, wherein the steel plate has a thickness of 100 to 200 mm.

[FIG.1]



INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2021/017472

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/58(2006.01)i; **C22C 38/50**(2006.01)i; **C22C 38/48**(2006.01)i; **C21D 8/04**(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 38/58(2006.01); C21D 8/02(2006.01); C22C 38/00(2006.01); C22C 38/04(2006.01); C22C 38/06(2006.01); C22C 38/12(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: 극후물(thick steel plate), 페라이트(ferrite), 펄라이트(pearlite), 마무리압연(finishing rolling)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2016-125077 A (NIPPON STEEL & SUMITOMO METAL) 11 July 2016 (2016-07-11) See paragraphs [0001], [0034] and [0074], claims 1 and 5 and table 2.	1-8
A	JP 2015-227483 A (NIPPON STEEL & SUMITOMO METAL) 17 December 2015 (2015-12-17) See claims 1-3 and table 2.	1-8
A	JP 3849244 B2 (JFE STEEL K.K.) 22 November 2006 (2006-11-22) See claims 1-2 and table 1.	1-8
A	JP 4329583 B2 (JFE STEEL K.K.) 09 September 2009 (2009-09-09) See claims 1 and 4-5.	1-8
A	KR 10-2020-0017025 A (POSCO) 18 February 2020 (2020-02-18) See claims 1 and 5.	1-8

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

* Special categories of cited documents:
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- "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)
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- "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
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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
14 March 2022	**15 March 2022**
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/KR2021/017472

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2016-125077 A	11 July 2016	JP 6007968 B2	19 October 2016
JP 2015-227483 A	17 December 2015	JP 5994819 B2	21 September 2016
JP 3849244 B2	22 November 2006	JP 11-092858 A	06 April 1999
JP 4329583 B2	09 September 2009	JP 2005-264208 A	29 September 2005
KR 10-2020-0017025 A	18 February 2020	KR 10-2153170 B1	26 October 2020

Form PCT/ISA/210 (patent family annex) (July 2019)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- KR 1020140003010 **[0013]**