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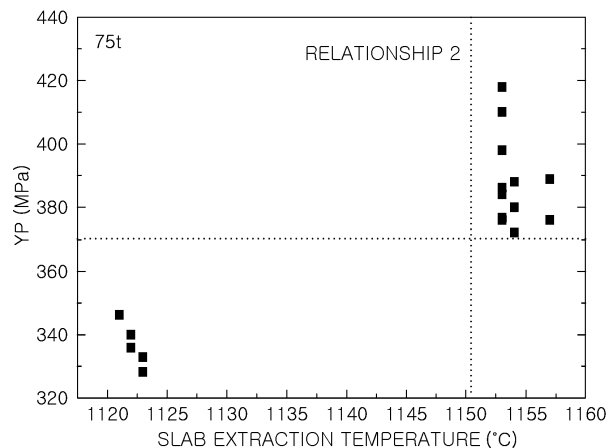
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(54) **STEEL MATERIAL HAVING HIGH STRENGTH AND EXCELLENT IMPACT TOUGHNESS, AND MANUFACTURING METHOD THEREFOR**

(57) The present invention relates to: a steel material having high strength and excellent impact toughness, the steel material being usable for a land wind power generator and the like; and a method for manufacturing same.

[FIG. 1]



Description**Technical Field**

5 **[0001]** The present disclosure relates to a steel material having high strength and excellent impact toughness, usable for a land-based wind power generator and the like; and a method for manufacturing the same.

Background Art

10 **[0002]** Recently, as a tower height of a land-based wind power generator has gradually become more advanced, demand for a thick, high strength steel material having excellent load resistance capacity has increased, and at the same time, a guarantee of impact toughness has also been required.

15 **[0003]** In order to realize high strength and excellent impact toughness of a steel material, refinement of a grain thereof is essential, and a rolling process may be one of various representative methods for the refinement of the grain. When rolling is performed at a temperature at which recrystallization may occur, a new fine grain of austenite may be generated using internal stress generated by a roll separation force, as a driving force. Meanwhile, a grain may receive stress by rolling in a temperature within a range in which recrystallization does not occur, to form a band structure in a rolling direction, and when many dislocations occur therein to undergo phase transformation of austenite, more nucleation sites may be provided to cause a grain refinement effect.

20 **[0004]** However, as a thickness of the steel material increases, a roll separation force that may be applied by rolling becomes limited, and as an internal structure, especially a central portion of the steel material is closer thereto, it may be less easy to form a fine grain by the rolling. This is because the grain of austenite tends to grow at temperatures equal to or higher than A_{e3} , as a temperature increases and a heating time period increases.

25 **[0005]** Meanwhile, it is often difficult to secure a grain having a sufficiently small size only by reheating and rolling of a slab, which may be processes in which refinement of a grain of austenite mainly occurs. In particular, as a temperature of the steel material to be rolled increases, deformation resistance during the rolling may decrease. For easy rolling, the reheating of the slab may be usually performed at a temperature much higher, as compared to the A_{e3} temperature, and at that time, the grain of austenite may grow significantly. When a grain refinement effect by rolling is not sufficient, an additional grain refining effect of austenite may be expected by a re-heating treatment after the rolling process, which generally may include a normalizing heat treatment.

30 **[0006]** As a material for a wind tower, a steel material that has been subjected to a normalizing heat treatment has traditionally been applied. However, when a heat treatment, as above, is applied during a manufacturing process, manufacturing costs may increase significantly. Accordingly, the material for a wind tower may not be easy to produce commercially, as compared to an as-rolled steel material or a thermo-mechanical controlled process (TMCP) steel material. Accordingly, there may be demand for manufacturing a steel material having properties, similar to those of a normalized heat-treated steel material without undergoing a normalizing heat treatment.

35 **[0007]** Patent Document 1 proposes a method of manufacturing a steel material having excellent impact toughness without a normalizing heat treatment. However, Patent Document 1 has a low carbon content, which is advantageous in securing sufficient low-temperature impact toughness, but it may be difficult to secure sufficient strength, and furthermore, there may be a limitation in that strength decreases significantly as thickness increases.

40 **[0008]** (Patent Document 1) Korean Registered Patent No. 10-1917453

Summary of Invention**Technical Problem**

45 **[0009]** An aspect of the present disclosure is to provide a steel material with excellent strength and impact toughness, even when a heat treatment process is omitted, and a method for manufacturing the same.

50 **[0010]** An object of the present disclosure is not limited to those mentioned above. The additional problems of the present disclosure may be described throughout the specification, and those skilled in the art will have no difficulty in understanding the additional problems of the present disclosure from those described in the specification of the present disclosure.

Solution to Problem

55 **[0011]** According to an aspect of the present disclosure, a steel material having high strength and excellent impact toughness, comprises, by weight, C: 0.12 to 0.18%, Si: 0.2 to 0.5%, Mn: 1.0 to 1.7%, P: 0.012% or less, S: 0.003% or less, Al: 0.015 to 0.045%, Nb: 0.02 to 0.05%, V: 0.01 to 0.08%, Ti: 0.005 to 0.017%, N: 0.002 to 0.01%, and a remainder

of Fe and inevitable impurities;

[0012] wherein a carbon equivalent (Ceq) of the following Relationship 1 is 0.48 or less,

[0013] a microstructure comprises 60 to 85% of ferrite by area fraction and remaining pearlite, and the microstructure includes at least one precipitate of NbC or VC, and a size of the precipitates is 50 nm or less:

[Relationship 1]

$$Ceq = C + Mn/6 + (Cr+Mo+V)/5 + (Cu+Ni)/15$$

[0014] Where C, Mn, Cr, Mo, V, Cu, and Ni are amounts (% by weight) of respective components.

[0015] According to another aspect of the present disclosure, a method of manufacturing a steel material having high strength and excellent impact toughness, comprises heating a steel slab comprising, by weight, C: 0.12 to 0.18%, Si: 0.2 to 0.5%, Mn: 1.0 to 1.7%, P: 0.012% or less, S: 0.003% or less, Al: 0.015 to 0.045%, Nb: 0.02 to 0.05%, V: 0.01 to 0.08%, Ti: 0.005 to 0.017%, N: 0.002 to 0.01%, and a remainder of Fe and inevitable impurities, and in which a carbon equivalent (Ceq) of the following Relationship 1 is 0.48 or less, under conditions of the following Relationship 2; and

[0016] rough-rolling the heated steel slab at a temperature within a range of 900 to 1100°C, and then finishing hot-rolling to Ar3 or higher after the rough-rolling:

[Relationship 1]

$$Ceq = C + Mn/6 + (Cr+Mo+V)/5 + (Cu+Ni)/15$$

[0017] Where C, Mn, Cr, Mo, V, Cu, and Ni are amounts (% by weight) of respective components.

Slab Extraction Temperature (°C) > $10300 / \{4.09 - \log([Nb][C]^{0.24}[N]^{0.65})\} - 273$

[0018] Where [Nb], [C], and [N] mean an amount (% by weight) in an alloy composition, respectively.

Advantageous Effects of Invention

[0019] According to the present disclosure, a steel material securing excellent strength and impact toughness without performing normalizing heat treatment after rolling may be provided, and may be widely used for a wind power structure or the like. In addition, a commercially useful steel material may be provided by reducing manufacturing costs by omitting a heat treatment.

[0020] Various advantages and effects of the present disclosure are not limited to those described above, and can be more easily understood through description of specific embodiments of the present disclosure.

Brief Description of Drawings

[0021] FIG. 1 is a graph illustrating a relationship between slab extraction temperature and yield strength, illustrated in an inventive example of the present disclosure.

Best Mode for Invention

[0022] Hereinafter, terms used in the present specification are for describing the present disclosure, and are not intended to limit the present disclosure. Additionally, as used herein, singular forms include plural forms unless relevant definitions clearly indicates the contrary.

[0023] The meaning of "including" or "comprising" used in the specification specifies a configuration, and does not exclude the presence or addition of another configuration.

[0024] Unless otherwise defined, all terms, including technical and scientific terms, used in the present specification have the same meaning as commonly understood by a person of ordinary skill in the technical field to which the present disclosure pertains. Terms defined in the dictionary may be interpreted to have meanings consistent with related technical literature and current disclosure.

[0025] The present inventors recognized that a normalized rolling (NR) method, as a manufacturing method in which

a steel material is hot-rolled and then air-cooled in a temperature within a range having properties, equal to or better than those of a normalized heat-treated steel material, without performing normalizing heat treatment after rolling, may secure properties, equal to or better than a normalizing heat treatment material, by establishment of an optimal component design and manufacturing conditions.

[0026] In particular, in structural steel used in a land-based wind tower or the like, as a large size and economic efficiency are required, a method is needed to secure properties required for a material thereof and manufacture the same economically. Accordingly, in an alloy design, it was confirmed that a steel material having target properties could be provided by identifying and optimizing an alloy composition and a relationship between some components and optimizing manufacturing conditions, leading to completion of the present disclosure.

[0027] Hereinafter, an embodiment of a steel material of the present disclosure will be described in detail.

[0028] First, an alloy composition of the steel material will be described in detail. The steel material of the present disclosure may comprise, by weight, C: 0.12 to 0.18%, Si: 0.2 to 0.5%. Mn: 1.0 to 1.7%, P: 0.012% or less, S: 0.003% or less, Al: 0.015 to 0.045%, Nb: 0.02 to 0.05%, V: 0.01 to 0.08%, Ti: 0.005 to 0.017%, and N: 0.002 to 0.01%; and

[0029] may further include one or more of Cu: 0.5% or less and Ni: 0.5% or less.

[0030] Carbon (C): 0.12 to 0.18% by weight (hereinafter, referred to as %, unless specifically mentioned in the present disclosure, an amount of each element is based on weight%).

[0031] C may be an element effective in improving strength of steel. For this purpose, C may be included in an amount of 0.12% or more. When an amount thereof exceeds 0.18%, a degree of segregation in a central portion of the steel may increase, and a martensite-austenite (MA) structure may be formed, which may significantly reduce low-temperature impact toughness. More advantageously, 0.17% or less may be included.

Silicon (Si): 0.2 to 0.5%

[0032] Si may not be only used as a deoxidizing agent, but may be also an element advantageous for improving strength and toughness of steel. To sufficiently obtain this effect, Si may be included in an amount of 0.2% or more. When an amount thereof exceeds 0.5%, there may be a risk of excessive formation of MA and poor low-temperature impact toughness. Therefore, Si may be in an amount of 0.2 to 0.5%.

Manganese (Mn): 1.0 to 1.7%

[0033] Mn may be an element advantageous for improving strength of steel by a solid solution strengthening effect. To fully obtain the effect, Mn may be included in an amount of 1.0% or more. When an amount thereof exceeds 1.7%, it combines with sulfur (S) in the steel to form MnS, which may greatly impair low-temperature impact toughness. Therefore, Mn may be included in an amount of 1.0 to 1.7%, and more advantageously, may be included in an amount of 1.35 to 1.65%.

Phosphorus (P): 0.012% or less

[0034] P may be an element advantageous in improving strength of steel and securing corrosion resistance thereof, but may greatly impair impact toughness of the steel. Therefore, it is desirable to limit an amount thereof as low as possible. In the present disclosure, even when P is included at a maximum of 0.012%, there may be no difficulty in securing target properties. Therefore, an amount thereof is limited to be 0.012% or less. Considering a level to be unavoidably added, 0% may be excluded.

Sulfur (S): 0.003% or less

[0035] S may be an element that greatly inhibits the hydrogen-induced cracking resistance and impact toughness of steel by combining with Mn in the steel to form MnS and the like. Therefore, it is advantageous to manage S in a low amount as possible. In the present disclosure, even when S is included at a maximum of 0.003%, there may be no difficulty in securing target properties. Therefore, an amount thereof is limited to be 0.003% or less. Considering a level to be unavoidably added, 0% may be excluded.

Aluminum (Al): 0.015 to 0.045%

[0036] Al may be an element that may inexpensively deoxidize molten steel. To sufficiently obtain the above-mentioned effect, Al may be included in an amount of 0.015% or more. When an amount thereof exceeds 0.045%, nozzle clogging may occur during continuous casting. This may be undesirable because not only does it cause damage, but impact toughness may be significantly reduced due to formation of Al-based oxidizing inclusions. Therefore, Al may be included

in 0.015 to 0.045%.

Niobium (Nb): 0.02 to 0.05%

5 **[0037]** Nb may precipitate to form NbC or Nb(C,N), greatly improving strength of a base material, and when reheated at high temperature, dissolved Nb may suppress recrystallization of austenite and transformation of ferrite or bainite to obtain a structure refinement effect. For this purpose, Nb may be included in an amount of 0.02% or more. When an amount thereof is excessive, undissolved Nb may form TiNb(C,N), which causes UT defects and impedes low-temperature impact toughness. Therefore, an upper limit of Nb may be 0.05%. More advantageously, Nb may contain 0.035 to 0.045%.

Vanadium (V): 0.01 to 0.08%

15 **[0038]** V may have a low solid solution temperature, as compared to other alloy elements, and may form VC during an air cooling process after hot-rolling, to contribute significantly to increasing strength. A steel material such as those of the present disclosure may not have sufficient strength after post-welding heat treatment (PWHT). Therefore, a strength improvement effect may be obtained by including 0.01% or more of V. When an amount thereof exceeds 0.08%, a fraction of a hard phase such as MA may increase, causing a problem in that low-temperature impact toughness is significantly reduced. Therefore, an amount of V may be 0.01 to 0.08%.

20 Titanium (Ti): 0.005 to 0.017%

25 **[0039]** Ti may be included together with N to form TiN, thereby reducing occurrence of surface cracks due to formation of AlN precipitates, and may be included in an amount of 0.005% or more. When an amount thereof exceeds 0.017%, coarse TiN may be formed during reheating of a steel slab, which acts as a factor in impeding low-temperature impact toughness. Therefore, Ti may be in an amount of 0.005 to 0.017%, and more preferably 0.01 to 0.015%.

Nitrogen (N): 0.002 to 0.01%

30 **[0040]** It may be advantageous that N may be included together with Ti to form TiN and suppress grain growth due to thermal effects during welding. To sufficiently obtain the above-described effects when adding Ti, N may be included in an amount of 0.002% or more. When an amount thereof exceeds 0.01%, it is undesirable because coarse TiN is formed and low-temperature impact toughness is impaired. Therefore, N may be in an amount of 0.002 to 0.01%.

35 **[0041]** Additionally, in addition to the above composition, one or more of copper (Cu): 0.5% or less and nickel (Ni) : 0.5% or less may be further included.

Copper (Cu): 0.5% or less

40 **[0042]** Cu may be an element that may greatly improve strength by solid solution strengthening. When an amount of Cu is excessive, it may not only impair weldability due to an increase in carbon equivalent, but also significantly deteriorate surface quality of a product. Therefore, when adding Cu, it may be included at a maximum of 0.5%. In the present disclosure, there may be no difficulty in securing target properties even when Cu is not added. Therefore, it is noted that Cu is not essential.

45 Nickel (Ni): 0.5% or less

[0043] Ni may be an element that may simultaneously improve strength of a base material and low-temperature impact toughness thereof, but may be an expensive element. When an amount thereof exceeds 0.5%, economic feasibility may be greatly reduced. Therefore, Ni may be included in an amount of 0.5% or less. In the present disclosure, there may be no difficulty in securing target properties even when Ni is not added. Therefore, it is noted that Ni is not essential.

50 **[0044]** The remainder may include iron (Fe) and inevitable impurities. Inevitable impurities may be unintentionally mixed in the normal steel manufacturing process, and, thus, may not be completely excluded, and any engineer in the normal steel manufacturing field can easily understand meaning thereof. In addition, the present disclosure does not completely exclude addition of compositions, other than the steel compositions mentioned above.

55 **[0045]** To secure impact toughness as well as a target level of strength in a steel material of the present disclosure, it is desirable to appropriately adjust amounts of elements advantageous for improving properties by adding a certain amount thereof. Therefore, a carbon equivalent (Ceq) of the following Relationship 1 may be 0.48 or less. When the carbon equivalent (Ceq) exceeds 0.48, it is advantageous in securing strength, but there may be a risk that properties

after welding may be greatly impaired. In addition, when large amounts of alloy elements are included, the costs will increase and economic feasibility will be impaired. Therefore, the carbon equivalent (Ceq) may be 0.48 or less.

[Relationship 1]

$$Ceq = C + Mn/6 + (Cr+Mo+V)/5 + (Cu+Ni)/15$$

[0046] Where C, Mn, Cr, Mo, V, Cu, and Ni are amounts (% by weight) of respective components.

[0047] A microstructure of the steel material of the present disclosure may include 60 to 85% of ferrite by area fraction and remaining pearlite. When the ferrite fraction is less than 60% or the remaining pearlite fraction exceeds 40%, it is advantageous to secure strength, but impact toughness may decrease significantly. In addition, when the ferrite fraction exceeds 85%, it is advantageous to secure impact toughness, but it is difficult to secure sufficient strength. Therefore, the steel material of the present disclosure may include 60 to 85 area % of ferrite and remaining pearlite.

[0048] A grain size of the ferrite may be 30μm or less. When an average grain size of the ferrite exceeds 30μm, it is difficult to secure yield strength, and impact toughness may be greatly reduced. Therefore, the average grain size may be 30μm or less.

[0049] The microstructure of the steel material may include a precipitate of NbC and/or VC. A size of the precipitate may be 50 nm or less. When the size of the precipitate exceeds 50 nm, it is undesirable because impact toughness may be greatly reduced. The precipitates may exist within a grain of ferrite.

[0050] When the steel material is evaluated perpendicular to a rolling direction at a t/4 point in a thickness direction (where t means a thickness (mm) of the steel material), a yield strength may be 370 MPa or more, a tensile strength may be 520 MPa or more, and an average Charpy impact absorption energy (CVN, -20°C) value at a temperature of -20°C may be 40J or more, to have excellent strength and low-temperature impact toughness.

[0051] Next, an embodiment of a method for manufacturing a steel material of the present disclosure will be described in detail. The above method may be manufactured by heating and hot-rolling a steel slab having an alloy composition, as described above, and a carbon equivalent (Ceq) of 0.48 or less in Relationship 1. Hereinafter, each process will be described in detail.

Heating of Steel Slab

[0052] Homogenization treatment may be performed by heating a steel slab satisfying an alloy composition, as described above. In this case, it is desirable to perform heating to satisfy temperature conditions defined by the following Relationship 2. A slab extraction temperature in the following Relationship 2 may not exceed 1200°C.

[0053] When a heating temperature of the steel slab does not satisfy the conditions of the following Relationship 2, a precipitate (carbide, nitride) formed in the slab may not be sufficiently re-dissolved, thereby reducing formation of precipitate in a process after hot-rolling, and it is ultimately difficult to satisfy specified yield strength and tensile strength presented in the present disclosure. When the slab extraction temperature exceeds 1200°C, a grain of austenite may coarsen and properties of the steel may deteriorate. Therefore, the slab extraction temperature may not exceed 1200°C.

$$\text{Slab Extraction Temperature (}^{\circ}\text{C)} > 10300 / \{4.09 - \log([Nb][C]^{0.24}[N]^{0.65})\} - 273$$

[0054] Where [Nb], [C], and [N] mean an amount (% by weight) in an alloy composition, respectively.

Hot-Rolling

[0055] The heated steel slab may be hot-rolled. The heated steel slab may be rough-rolled at a temperature within a range of 900 to 1100°C, and may be then finish hot-rolled to Ar3 or higher. When a temperature during the rough-rolling may be less than 950°C, there may be a problem in that the temperature becomes too low during the subsequent finishing hot-rolling. When a temperature during the finishing hot-rolling is lower than Ar3, a rolling load may increase and there may be a risk of quality defects such as surface cracks or the like.

$$Ar3 = 910 - 310C - 80Mn - 20Cu - 55Ni - 80Mo + 119V + 124Ti - 18Nb + 179Al$$

[0056] Where each element means an amount (% by weight)

[0057] After the hot-rolling, air cooling may be performed.

[0058] The steel material of the present disclosure manufactured by the above method may secure high strength and excellent impact toughness without performing subsequent heat treatment, such as normalizing heat treatment or the like.

Mode for Invention

[0059] Next, examples of the present disclosure will be described.

[0060] Various modifications to the following examples may be made by those skilled in the art without departing from the scope of the present disclosure. The following examples are for understanding of the present disclosure, and the scope of the present disclosure should not be limited to the following examples, but should be determined by the claims described below as well as their equivalents.

(Example 1)

[0061] A slab was manufactured by continuously casting molten steel having an alloy composition (% by weight, the remainder being Fe and inevitable impurities) illustrated in Table 1 below. In this case, the slab was manufactured to have a thickness of 300 mm. In Table 1, Inventive Examples 1 to 4 were cases in which both the alloy composition and Relationship 1 presented in the present disclosure were satisfied, Comparative Example 1 was a case in which an amount of C and Relationship 1 were outside the values presented in the present disclosure, and Comparative Example 3 indicates that an amount of Nb was outside the value presented in the present disclosure.

[Table 1]

	C	Si	Mn	P	S	Al	Nb	Cu	Ni	V	Ti	N	Relationship 1
Inventive Example 1	0.1 50	0.4 50	1.5 30	0.0 08	0.0 02	0.0 30	0.0 45	0.0 00	0.0 00	0.0 40	0.0 12	0.0 035	0.413
Inventive Example 2	0.1 60	0.4 50	1.6 50	0.0 08	0.0 02	0.0 30	0.0 45	0.0 00	0.0 00	0.0 40	0.0 12	0.0 036	0.443
Inventive Example 3	0.1 55	0.4 50	1.6 00	0.0 09	0.0 02	0.0 30	0.0 35	0.0 00	0.0 00	0.0 55	0.0 12	0.0 035	0.433
Inventive Example 4	0.1 60	0.4 00	1.6 50	0.0 08	0.0 02	0.0 30	0.0 45	0.1 00	0.2 00	0.0 45	0.0 12	0.0 035	0.464
Comparative Example 1	0.1 85	0.4 00	1.6 50	0.0 09	0.0 02	0.0 30	0.0 40	0.1 00	0.1 50	0.0 45	0.0 12	0.0 036	0.486
Comparative Example 2	0.1 50	0.4 50	1.6 00	0.0 08	0.0 02	0.0 30	0.0 45	0.0 00	0.0 00	0.0 30	0.0 12	0.0 035	0.423
Comparative Example 3	0.1 60	0.4 50	1.5 50	0.0 08	0.0 02	0.0 30	0.0 15	0.0 00	0.0 00	0.0 35	0.0 12	0.0 036	0.425

[0062] In Table 1 above, Relationship 1 may be calculated as follows:

$$Ceq = C + Mn/6 + (Cr+Mo+V)/5 + (Cu+Ni)/15$$

[0063] Where C, Mn, Cr, Mo, V, Cu, and Ni are amounts (% by weight) of respective components.

[0064] The slab was heated and rough-rolled under conditions in Table 2, finish hot-rolled at a temperature within a range of 880 to 900°C to produce a hot-rolled steel sheet having a thickness of 5 mm, and air-cooled to room temperature. Inventive Examples 1 to 4 and Comparative Examples 1 and 3 satisfied the process conditions presented in the present disclosure, but Comparative Example 2 did not satisfy the conditions of Relationship 2 below.

[Table 2]

	Extraction Temp. (°C)	Furnace Time (min.)	Remaining Reduction Ratio (%)	Roll Start Temp. (°C)	Roll Finish Temp. (°C)	Relationship 2	Satisfaction of Relationship 2
Inventive Example 1	1161	362	50	930	900	1151	○
Inventive Example 2	1165	360	50	928	898	1154	○
Inventive Example 3	1160	360	50	915	880	1131	○
Inventive Example 4	1162	362	50	920	890	1153	○
Comparative Example 1	1160	362	50	920	890	1147	○
Comparative Example 2	1125	360	50	925	895	1151	X
Comparative Example 3	1164	361	50	930	900	1066	○

[0065] In Table 2 above, Relationship 2 may be as follows:

$$\text{Slab Extraction Temperature (°C)} > 10300 / \{4.09 - \log([Nb][C]^{0.24}[N]^{0.65})\} - 273$$

[0066] Where [Nb], [C], and [N] mean an amount (% by weight) in an alloy composition, respectively.

[0067] A microstructure and mechanical properties of a steel material manufactured as above were evaluated. The microstructure was observed using an optical microscope, and then a fraction and diameter of ferrite grains were measured using an analysis program, and an average diameter of a precipitate was measured using a transmission electron microscope. In this case, the microstructure was measured at a point $t/4$ (t may be the steel thickness, mm) in the thickness direction of each steel material, and the results may be illustrated in Table 3 below.

[0068] In addition, the mechanical properties were evaluated at a $1/4t$ point in a thickness direction of each steel material. In this case, tensile specimens were collected from each thickness direction point in a direction, perpendicular to a rolling direction, to measure tensile strength (TS), yield strength (YS), and elongation (El) was measured, and the impact specimen was taken from a JIS No. 4 standard test specimen at a $1/4t$ point in the thickness direction in the rolling direction, and the average impact toughness (CVN) at -20°C was measured. The results may be illustrated in Table 4 below.

[Table 3]

	Microstructure			
	Polygonal Ferrite (area %)	Pearlite (area %)	Grain Size of Ferrite (μm)	Size of Precipitate (nm)
Inventive Example 1	80	20	26	35
Inventive Example 2	76	24	22	34
Inventive Example 3	77	23	27	42
Inventive Example 4	76	24	20	41
Comparative Example 1	68	32	36	67
Comparative Example 2	81	19	28	36
Comparative Example 3	76	24	34	30

[0069] As illustrated in Table 3, Inventive Steels 1 to 4 manufactured according to the alloy composition, component relationship, and manufacturing conditions, proposed in the present disclosure, satisfied a fraction, a grain size, and a precipitate size of polygonal ferrite proposed in the present disclosure. Comparative Examples 1 and 3 were satisfied with the polygonal ferrite fraction, but a grain size of ferrite was outside the value presented in the present disclosure. Additionally, Comparative Example 1 deviated from a size of the precipitate presented in the present disclosure.

[Table 4]

	As-rolled				Normalized			
	Tensile Properties			Impact Toughness (J)	Tensile Properties			Impact Toughness (J)
	YP (MPa)	TS (MPa)	El.(%)		YP (MPa)	TS (MPa)	El.(%)	
Inventive Example 1	383	536	27	210	377	524	28	223
Inventive Example 2	402	552	26	196	396	530	27	200
Inventive Example 3	410	556	25	174	400	542	26	186
Inventive Example 4	401	548	26	195	393	529	27	203
Comparative Example 1	410	544	24	35	374	524	24	42
Comparative Example 2	336	497	29	168	316	488	30	173
Comparative Example 3	351	520	26	75	330	509	28	94

[0070] Table 4 above illustrates tensile properties and low-temperature impact toughness before and after normalizing. In this case, normalizing treatment was held at 870°C for 128 minutes, and was then air-cooled.

[0071] In Inventive Examples 1 to 4, a component range, Relationships 1 and 2, and microstructure properties presented in the present disclosure were satisfied, and both tensile properties and low-temperature impact toughness were satisfied. Specifically, in Inventive Examples 1 to 4, when comparing results after as-rolled and normalizing heat treatment, yield strength and tensile strength slightly decreased after heat treatment, but still satisfy the strength presented in the present disclosure. Impact toughness increased slightly, as compared to those manufactured by an NR method after heat treatment, and it can be confirmed that impact toughness presented by the present disclosure was satisfied.

[0072] In Comparative Example 1, as component systems in which an amount of C and Relationship 1 were outside the range presented in the present disclosure, but it can be confirmed that yield/tensile strength satisfied the values presented in the present disclosure due to excessive addition of C, and impact toughness did not satisfy the values. Comparative Example 2 satisfied all of the component ranges presented in the present disclosure, but did not satisfy Relationship 2 to have a very low slab extraction temperature. It can be confirmed that, after both as-rolled and normalizing heat treatments, yield strength and tensile strength presented in the present disclosure were lowered. In addition, it can be confirmed that a decrease in yield strength was very large, as compared to Inventive Examples 1 to 4. This was believed to be due to a significant decrease in strength as Nb was not sufficiently dissolved in the slab and NbC was not sufficiently precipitated during rolling. Comparative Example 3 was a case in which an amount of Nb deviated from the value presented in the present disclosure. Even though Nb was heated at a temperature at which Nb was sufficiently dissolved in a slab, an amount itself was very low and an NbC precipitate was not sufficiently precipitated. Therefore, it can be confirmed that the NbC precipitate was not sufficiently precipitated, and yield strength and tensile strength were not satisfied, and in Comparative Example 3, it can also be confirmed that yield strength decreased significantly after normalizing heat treatment.

(Example 2)

[0073] As a separate example, a steel material having a thickness of 75 mm was manufactured by rolling a slab having the components of Inventive Example 1 of Example 1. In this case, to confirm yield strength according to a slab extraction temperature, when results of Relationship 2 of the extraction temperature were varied, results of relationship between an extraction temperature and yield strength were illustrated in FIG. 1. It can be confirmed that, when the extraction temperature did not satisfy Relationship 2, yield strength presented in the present disclosure did not satisfy, whereas when the extraction temperature satisfied Relationship 2, all exhibited excellent yield strength.

Claims

1. A steel material having high strength and excellent impact toughness, comprising:

by weight, C: 0.12 to 0.18%, Si: 0.2 to 0.5%, Mn: 1.0 to 1.7%, P: 0.012% or less, S: 0.003% or less, Al: 0.015 to 0.045%, Nb: 0.02 to 0.05%, V: 0.01 to 0.08%, Ti: 0.005 to 0.017%, N: 0.002 to 0.01%, and a remainder of

Fe and inevitable impurities;
wherein a carbon equivalent (Ceq) of the following [Relationship 1] is 0.48 or less,
a microstructure comprises 60 to 85% of ferrite by area fraction and remaining pearlite, and the microstructure
includes at least one precipitate of NbC or VC, and a size of the precipitates is 50 nm or less:

[Relationship 1]

$$Ceq = C + Mn/6 + (Cr+Mo+V)/5 + (Cu+Ni)/15$$

Where C, Mn, Cr, Mo, V, Cu, and Ni are amounts (% by weight) of respective components.

2. The steel material of claim 1, further comprising at least one of Cu: 0.5% or less or Ni: 0.5% or less.
3. The steel material of claim 1, wherein a grain size of the ferrite is 30um or less.
4. The steel material of claim 1, wherein the at least one precipitate of NbC or VC is provided in a grain of the ferrite.
5. The steel material of claim 1, wherein, when the steel material is evaluated perpendicular to a rolling direction at a t/4 point in a thickness direction (where t means a thickness (mm) of the steel material), a yield strength is 370 MPa or more, a tensile strength is 520 MPa or more, and an average Charpy impact absorption energy (CVN, -20°C) value at a temperature of -20°C is 40J or more.
6. A method of manufacturing a steel material having high strength and excellent impact toughness, comprising:
heating a steel slab comprising, by weight, C: 0.12 to 0.18%, Si: 0.2 to 0.5%, Mn: 1.0 to 1.7%, P: 0.012% or less, S: 0.003% or less, Al: 0.015 to 0.045%, Nb: 0.02 to 0.05%, V: 0.01 to 0.08%, Ti: 0.005 to 0.017%, N: 0.002 to 0.01%, and a remainder of Fe and inevitable impurities, and in which a carbon equivalent (Ceq) of the following [Relationship 1] is 0.48 or less, under conditions of the following [Relationship 2]; and
rough-rolling the heated steel slab at a temperature within a range of 900 to 1100°C, and then finishing hot-rolling to Ar3 or higher after the rough-rolling:

[Relationship 1]

$$Ceq = C + Mn/6 + (Cr+Mo+V)/5 + (Cu+Ni)/15$$

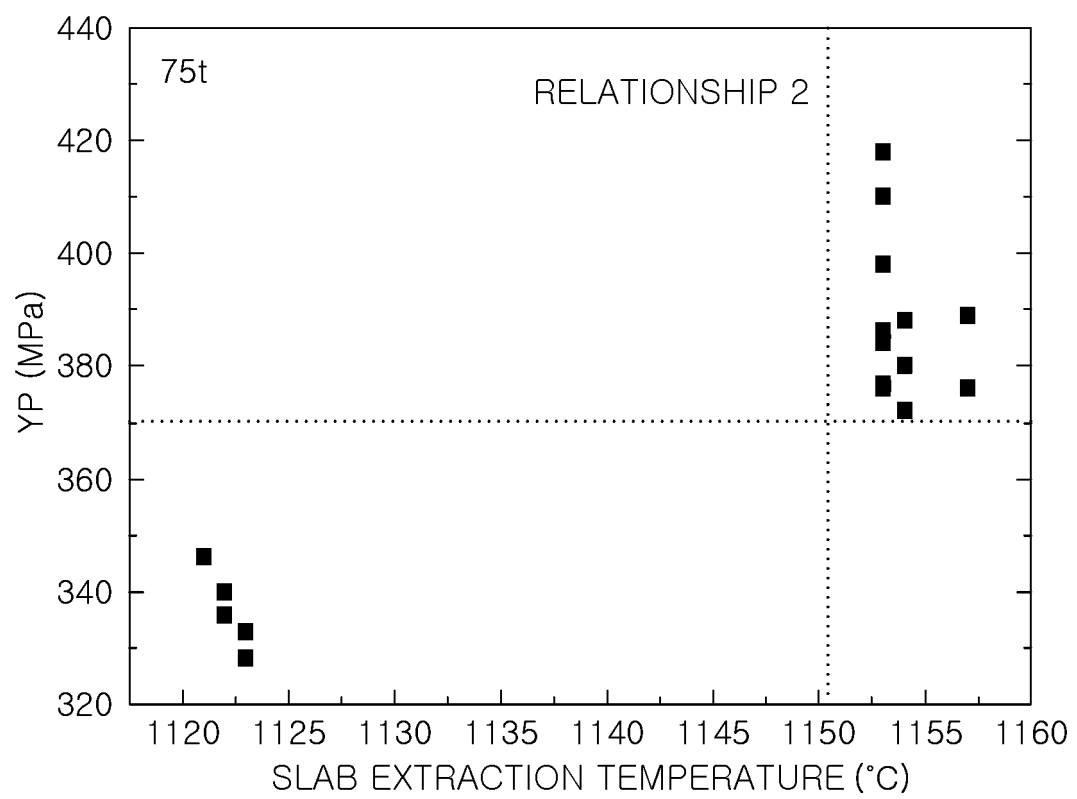
Where C, Mn, Cr, Mo, V, Cu, and Ni are amounts (% by weight) of respective components.

$$\text{Slab Extraction Temperature (}^{\circ}\text{C)} > 10300 / \{4.09 - \log([Nb][C]^{0.24}[N]^{0.65})\} - 273$$

Where [Nb], [C], and [N] mean an amount (% by weight) in an alloy composition, respectively.

7. The method of claim 6, wherein the steel slab further comprises at least one of Cu: 0.5% or less or Ni: 0.5% or less.
8. The method of claim 6, wherein the slab extraction temperature is 1200°C or lower.

[FIG. 1]



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2022/016882

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/04(2006.01)i; **C22C 38/02**(2006.01)i; **C22C 38/06**(2006.01)i; **C22C 38/12**(2006.01)i; **C22C 38/14**(2006.01)i;
C21D 8/02(2006.01)i; **C21D 9/46**(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/04(2006.01); C21D 8/02(2006.01); C21D 8/06(2006.01); C22C 38/00(2006.01); C22C 38/58(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: 고강도(high strength), 충격인성(impact toughness), 페라이트(ferrite), 펄라이트(pearlite)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	KR 10-1205144 B1 (HYUNDAI STEEL COMPANY) 26 November 2012 (2012-11-26) See paragraphs [0001]-[0003], [0058], [0080], [0082] and [0087] and claims 1-5.	1-8
Y	KR 10-2015-0026581 A (DONGKUK STEEL MILL CO., LTD.) 11 March 2015 (2015-03-11) See paragraphs [0035]-[0036] and claim 1.	1-8
A	JP 2003-003229 A (NIPPON STEEL CORP.) 08 January 2003 (2003-01-08) See claims 1-2 and 4 and tables 2 and 4.	1-8
A	JP 2016-125077 A (NIPPON STEEL & SUMITOMO METAL) 11 July 2016 (2016-07-11) See claims 1-2 and 5.	1-8
A	JP 11-315341 A (KAWASAKI STEEL CORP.) 16 November 1999 (1999-11-16) See paragraphs [0027]-[0028] and claim 1.	1-8

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

* Special categories of cited documents:	"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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
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"E" earlier application or patent but published on or after the international filing date	"&" document member of the same patent family
"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	

Date of the actual completion of the international search 31 January 2023	Date of mailing of the international search report 31 January 2023
Name and mailing address of the ISA/KR Korean Intellectual Property Office Government Complex-Daejeon Building 4, 189 Cheongsaro, 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/KR2022/016882

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REFERENCES CITED IN THE DESCRIPTION

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