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(54) Titre : PROCEDE DE PRODUCTION DE PLAQUES D'ACIER A HAUTE RESISTANCE DE 780MPA PRESENTANT UNE EXCELLENTE RESILIENCE AUX BASSES TEMPERATURES

(54) Title: METHOD OF PRODUCTION OF 780 MPA CLASS HIGH STRENGTH STEEL PLATE EXCELLENT IN LOW TEMPERATURE TOUGHNESS

(57) Abrégé/Abstract:
A process for the production of 780PMa-grade high-tensile -strength steel plates excellent in low-temperature toughness, which comprises heating a steel bloom which contains by mass C: 0.06 to 0.15%, Si: 0.05 to 0.35%, Mn: 0.60 to 2.00%, P: 0.015% or less, S: 0.015% or less, Cu: 0.1 to 0.5%, Ni: 0.1 to 1.5%, Cr: 0.05 to 0.8%, Mo: 0.05 to 0.6%, Nb: less than 0.005%, V: 0.005 to 0.060%, Ti: less than 0.003%, Al: 0.02 to 0.10%, B: 0.0005 to 0.003%, and N: 0.002 to 0.006% to a temperature of 1050 to 1200°C; completing the hot rolling of the bloom at 870°C or above; cooling, after a lapse of 10 to 90 seconds, the obtained plate at a cooling rate of 5°C/s or above from a temperature of 840°C or above to a temperature of 200°C or below; and then tempering the resulting plate at a temperature of 450 to 650°C for 20 to 60 minutes.

ABSTRACT

A method of production of 780 MPa class high strength steel plate excellent low temperature toughness comprising heating a steel slab of containing, by mass%, C: 0.06 to 0.15%, Si: 0.05 to 0.35%, Mn: 0.60 to 2.00%, P: 0.015% or less, S: 0.015% or less, Cu: 0.1 to 0.5%, Ni: 0.1 to 1.5%, Cr: 0.05 to 0.8%, Mo: 0.05 to 0.6%, Nb: less than 0.005%, V: 0.005 to 0.060%, Ti: less than 0.003%, Al: 0.02 to 0.10%, B: 0.0005 to 0.003%, and N: 0.002 to 0.006% to 1050°C to 1200°C in temperature, hot rolling ending at 870°C or more, waiting for 10 seconds to 90 seconds, then cooling from 840°C or more in temperature by a 5°C/s or more cooling rate to 200°C, then tempering at 450°C to 650°C in temperature for 20 minutes to 60 minutes.

DESCRIPTION

METHOD OF PRODUCTION OF 780 MPA CLASS HIGH STRENGTH STEEL PLATE EXCELLENT IN LOW TEMPERATURE TOUGHNESS

Technical Field

The present invention relates to a method of production of excellent low temperature toughness and 780 MPa class high strength steel plate for offshore structures and penstocks etc.

Background Art

To produce a steel plate having a tensile strength of the 780 MPa class and having excellent low temperature toughness, refinement of the quenched structure (lower bainite or martensite) is said to be effective. To refine a quenched structure, it is necessary to refine the austenite grain size before the formation of the quenched structure before cooling the steel material.

In particular, when producing a plate by direct quenching (DQ), controlled rolling may be used to control the austenite grain size. By rolling in the austenite recrystallization region, refinement of the austenite grain size before the formation of the quenched structure becomes possible.

However, it is difficult to obtain a grasp of the austenite recrystallization region and pre-recrystallization region of austenite of a steel before rolling. Variation in the austenite grains is liable to invite instability in the quality of steel.

On the other hand, by making maximum use of controlled rolling and refining the structure, excellent low temperature toughness should be able to be secured. For example, Japanese Patent Publication (A) No. 6-240355 discloses performing final rolling of a steel plate containing Nb at the pre-recrystallization region of austenite of 780°C or less so as to achieve refinement of structure of thick-gauge steel plate and secure excellent low temperature toughness at the center of plate thickness.

However, with this method of production, the quenchability greatly falls and a ferrite structure is mainly formed, so it is difficult to secure a 780 MPa class high strength and high toughness. Furthermore, rolling at a low temperature becomes necessary, so there is also a problem from the viewpoint of the productivity.

Further, the Nb added for refining the structure is extremely high in effect of hardening the welding heat affected zone (HAZ). As a result, it causes deterioration of the HAZ toughness. In particular, with high strength steel such as the 780 MPa class steel, the deterioration in HAZ toughness due to this effect becomes an extremely great problem.

To obtain a 780 MPa class strength, it is effective to add B having a large effect in raising the quenchability. However, as described in Japanese Patent Publication (A) No. 2007-138203, B promotes the formation of a hardened second phase due to the simultaneous addition of Nb. The deterioration of the HAZ toughness became a particular problem as a result.

To improve the HAZ toughness, it is known that addition of Ti is effective. This is because Ti bonds with N etc. to form fine precipitates and has the effect of restraining grain growth. However, as described in Japanese Patent Publication (A) No. 2000-8135, in the case of steel containing C in 0.2% or more for the purpose of securing the strength, extremely hard grains of TiC are formed at the base metal and HAZ. This has the problem of causing a deterioration of toughness.

In the above way, up to now, the fact is that no method of production of 780 MPa class high strength steel plate free of Nb, free of Ti, and provided with both high strength and excellent low temperature toughness has yet been proposed.

Disclosure of Invention

The present invention, in view of the above situation, provides a method of production of 780 MPa class high strength steel plate excellent in low temperature toughness suitable for thick-gauge steel plate for offshore structures and penstocks etc. which is Nb-free, is Ti-free, and is provided with both high strength and excellent low temperature toughness even at the center part of the plate thickness of the 780 MPa class high strength steel plate.

The inventors, to solve the above problems, rolled steel not containing Nb or Ti for refining the austenite grain size under suitable rolling conditions. As a result, they discovered that by making maximum use of the effect of improvement of quenchability of B to obtain a quenched structure and making the microstructure finer, it is possible to obtain both high strength and high toughness and that by making the steel Nb and Ti free, it becomes possible to avoid deterioration of toughness due to these, and therefore it becomes possible to produce 780 MPa class high strength steel plate stably securing high strength and excellent low temperature toughness even at the center part of plate thickness and thereby completed the present invention.

The gist of the present invention is as follows:

(1) A method of production of 780 MPa class high strength steel plate excellent in low temperature toughness characterized by heating a steel slab of chemical compositions containing, by mass%,

C: 0.06 to 0.15%,
Si: 0.05 to 0.35%,
Mn: 0.60 to 2.00%,
P: 0.015% or less,
S: 0.015% or less,
Cu: 0.1 to 0.5%,
Ni: 0.1 to 1.5%,

Cr: 0.05 to 0.8%,
Mo: 0.05 to 0.6%,
Nb: less than 0.005%,
V: 0.005 to 0.060%,
Ti: less than 0.003%,
Al: 0.02 to 0.10%,
B: 0.0005 to 0.003%, and
N: 0.002 to 0.006%,
having a balance of iron and unavoidable impurities, and
having a BNP defined by
BNP=(N-(14/48)Ti)/B
of over 1.5 to less than 4.0,
to 1050°C to 1200°C in temperature, hot rolling ending at 870°C or more, waiting for 10 seconds to 90 seconds, then cooling from 840°C or more in temperature by a 5°C/s or more cooling rate to 200°C, then tempering at 450°C to 650°C in temperature for 20 minutes to 60 minutes

(2) A method of production of 780 MPa class high strength steel plate excellent in low temperature toughness as set forth in (1) characterized in that said steel slab further contains, by mass%, one or more of
Ca: 0.0035% or less and
REM: 0.0040% or less.

Best Mode for Carrying Out the Invention

Below, embodiments of the present invention will be explained.

The present invention makes the steel Nb-free and Ti-free to avoid the excessive refinement of the old austenite grain size and makes maximum use of B to secure quenchability so can stably secure high strength and high low temperature toughness even at the center part of plate thickness.

In a steel material suitable for steel plate etc. for offshore structures, penstocks, etc. covered by the present invention, a 780 MPa class high strength and toughness of the base material and HAZ at -40°C are demanded. To secure a high strength, it is necessary to increase the Nb, Ti, and other alloy elements and water cool the steel to obtain a quenched structure such as a lower bainite structure and martensite structure, but if the contents of the alloy elements are high, it is difficult to secure toughness. In particular, securing low temperature HAZ toughness becomes a problem.

To achieve both a high strength and low temperature HAZ toughness, it is necessary to secure strength without using expensive alloy elements as much as possible. As one proposal for solving this, there is use of B. This has been practiced in the past.

It is known that B segregates at the austenite grain boundaries and stabilizes the grain boundaries, so suppresses transformation from the grain boundaries, increases the quenchability, and, in particular when the amount of solid solution B becomes 0.0005% or more, gives the effect of a high improvement in quenchability. For this reason, there was the problem that if making extensive use of controlled rolling, the austenite grains became finer and the austenite grain boundary area increased resulting in an insufficient amount of segregation of solid solution B at the grain boundaries and a large amount of dislocations were introduced into the austenite resulting in promotion of pipe diffusion and the difficult of segregation of solid solution B at the austenite grain boundaries as a result of which the predetermined quenchability could not be obtained and the material quality varied. In addition, B is an element exhibiting its effects in fine amounts, so reacts sensitively with fine differences in conditions. Therefore, to stably make use of B, it is effective not to make the austenite grains finer and not to introduce large amounts of dislocations.

The inventors discovered that by rolling steel under suitable rolling conditions without adding Nb or Ti for refining the austenite grain size and as a result making maximum use of the effect of improvement of quenchability by B to obtain a quenched structure and refine the lower structure, it is possible to achieve both a high strength and high toughness. Furthermore, by making the steel Nb- and Ti-free, it becomes possible to avoid deterioration of toughness due to the same. Further, the inventors discovered that by rolling under suitable rolling conditions and securing an austenite grain size of 50 μm or more, it is possible to cause the solid solution B required for securing quenchability to segregate in a sufficient amount at the austenite grain boundaries. Note that, to secure a 780 MPa class strength, in addition to securing the quenchability by B, it is necessary to make the carbon equivalent (Ceq) expressed by the following formula (1) 0.41 to 0.61. The lower limit may be set to 0.42% and the upper limit to 0.54%.

$$Ceq=\%C+\%Mn/6+(\%Cu+\%Ni)/15+(\%Cr+\%Mo+\%V)/5\ldots \text{ formula (1)}$$

Below, the reasons for limitation of the present invention will be explained. First, the reasons for limitation of the composition of the steel material of the present invention will be explained. The % in the following compositions means mass %.

C: 0.06 to 0.15%

C is an element necessary for securing strength. 0.06% or more has to be added, but addition of a large amount is liable to invite a deterioration of low temperature toughness, in particular a deterioration of the HAZ toughness, so the upper limit is made 0.15%. Preferably, the lower limit is set to 0.08% or 0.09% and the upper limit is set to 0.12% or 0.11%.

Si: 0.05 to 0.35%

Si is an element effective as a deoxidizing element or for increasing the strength of the steel by solution strengthening, but with less than a 0.05% content, these effects are small, while if over 0.35% is included, the HAZ toughness is degraded. For this reason, Si was limited to 0.05 to 0.35%. Preferably, the lower limit is set to 0.10% and the upper limit is set to 0.30% or 0.25%.

Mn: 0.60 to 2.00%

Mn is an element effective for increasing the strength for raising the strength of the steel. From the viewpoint of securing the quenchability, a 0.60% or more content is necessary. However, if adding over 2.00% of Mn, the toughness deteriorates. For this reason, Mn was limited to 0.60 to 2.00%. Preferably, the lower limit is set to 0.70% or 0.80% and the upper limit is set to 1.20% or 1.00%.

P: 0.015% or less

P segregates at the grain boundaries to degrade the toughness of the steel, so should be reduced as much as possible, but up to 0.015% is allowable, so the content was limited to 0.015% or less. Preferably, the upper limit is set to 0.010% or 0.008%.

S: 0.015% or less

S mainly forms MnS and remains in the steel and has the action of making the structure finer after rolling and cooling, but a content of 0.015% or more reduces the toughness and ductility in the plate thickness direction. To avoid this, S has to be 0.015% or less, so S was limited to 0.015% or less. Preferably, the upper limit is set to 0.010%, 0.006%, or 0.003%.

Cu: 0.1 to 0.5%

Cu is an element effective for securing the strength of steel plate by solution strengthening and precipitation strengthening. A content of 0.10% or more is necessary, but addition of 0.50% or more is liable to reduce the hot workability. For this reason, Cu was limited to 0.1 to 0.5%. Preferably, the lower limit is set to 0.15% and the upper limit is set to 0.3%.

Ni: 0.1 to 1.5%

Ni is effective for securing the strength and low temperature toughness of the steel plate. A content of 0.10% or more is necessary. However, this is an extremely expensive element, so addition of 1.50% or more invites a great increase in costs. For this reason, Ni was limited to 0.1 to 1.5%. Preferably, the lower limit is set to 0.25%, and the upper limit is set to 1.2%, more preferably the lower limit is set to 0.65% and the upper limit is set to 0.95%.

Cr: 0.05 to 0.8%

Cr is an element effective for securing the strength of the steel plate mainly by solution strengthening. A content of 0.05% or more is necessary, but addition of 0.8% or more impairs the workability and weldability of the steel plate and invites a rise in costs. For this reason, Cr was limited to 0.05 to 0.8%. Preferably, the lower limit is set to 0.20% or 0.30% and the upper limit is set to 0.60% or 0.45%.

Mo: 0.05 to 0.6%

Mo is an element effective for securing the strength of the steel plate by precipitation strengthening or solution strengthening. A content of 0.05% or more is necessary, but addition of 0.60% or more detracts from the workability of the steel plate and greatly increases the cost. For this reason, Mo was limited to 0.05 to 0.6%. Preferably, the lower limit is set to 0.25 or 0.30% and the upper limit is set to 0.50% or 0.45%.

Nb: less than 0.005%

Nb enlarges the pre-recrystallization region of austenite and promotes the increased fineness of the grains of ferrite, so invites a drop in the quenchability. Further, the Nb carbides result in easier HAZ embrittlement, so this is preferably not included as much as possible. However, 0.005% is allowable, so Nb was limited to less than 0.005%. The content is preferably 0.003% or less, more preferably 0.002% or less.

V: 0.005 to 0.060%

V is an element effective for securing the strength of steel plate by precipitation strengthening. A content of 0.005% or more is necessary, but addition of 0.060% or more impairs the weldability and toughness of the steel plate, so V was limited to 0.005 to 0.060%. Preferably, the lower limit is set at 0.025% or 0.035% and the upper limit is set at 0.050%.

Ti: less than 0.003%

Ti bonds with C to form TiC and is thereby liable to degrade the base material toughness. In particular, this is remarkable in a 780 MPa class strength steel material, so this element is preferably not contained much at all. However, less than 0.003% is allowable, so Ti was limited to less than 0.003%. The content is preferably 0.002% or less.

Al: 0.02 to 0.10%

Al bonds with N to form AlN and thereby has the effect of avoiding rapid coarsening of the austenite grain size at the time of reheating, so addition of 0.02% or more is necessary, but addition of 0.10% is liable to form coarse inclusions and degrade the toughness. For this reason, Al was limited to 0.02 to 0.10%. To improve the strength and toughness of the center part of plate thickness, preferably the content is 0.04 to 0.08%, more preferably 0.05% to 0.08% or 0.06 to 0.08%.

B: 0.0005 to 0.003%

B is an element required for securing quenchability. To secure the amount of solid solution B of 0.0005% required to obtain a sufficient effect of improvement of the quenchability at the center part of the plate thickness, addition of 0.0005% or more is necessary. However, with addition of 0.003% or more, due to the excessive B, the quenchability excessively rises. Due to this, the toughness becomes low. Further, the excessive B forms coarse nitrides which are liable to degrade the toughness. For this reason, B was limited to 0.0005 to 0.003%. To improve the strength and toughness at the center part of the plate thickness, the content is preferably 0.0005 to 0.002% or 0.0005 to 0.0015%.

N: 0.002 to 0.006%

N bonds with Al to form AlN and thereby has the effect of avoiding rapid coarsening of the austenite grain size at the time of reheating, but addition of 0.006% or more is liable to result in bonding with B and reduction of the amount of solid solution B inviting a drop in quenchability. For this reason, N was limited to 0.002 to 0.006%. Preferably, the lower limit is set to 0.002% and the upper limit to 0.004%.

BNP: over 1.5 to less than 4.0

BNP is a parameter shown by the following formula (2) for finding the balance of Ti, N, and B required for securing the quenchability. With 1.5 or less, B becomes excessive and invites a deterioration of toughness, while with 4.0 or more, the insufficient solid solution B causes sufficient quenchability to be unable to be obtained. For this reason, BNP was limited to over 1.5 to less than 4.0. To improve the strength and toughness of the center part of the steel plate, preferably the lower limit is set to 1.8, 2.0 or more and the upper limit is set to 3.6, 3.2 or 2.8.

$$BNP=(N-(14/48)Ti)/B \quad \cdots\cdots \quad (2)$$

The above are essential elements in the present invention. Addition of the following elements is also effective in a range not detracting from these effects.

Addition of one or both of Ca: 0.0035% or less and REM: 0.0040% or less.

By addition of Ca, the form of the MnS is controlled and the low temperature toughness is further improved, so this can be selectively added when strict HAZ characteristics are required. Furthermore, an REM enables formation of fine oxides and fine sulfides in the molten steel and their stable presence later as well, so act effectively as pinning particles in the HAZ and in particularly have an action of improving the large heat input weld toughness, so can be selectively added when particularly excellent toughness is required.

On the other hand, with addition of Ca over 0.0035%, the cleanliness of the steel is impaired and the toughness is degraded and susceptibility to hydrogen induced cracking ends up being raised, therefore 0.0035% was made the upper limit. If the REM is added over 0.0040%, the precipitates become excessive and are liable to cause reduction of area at the time of casting, so 0.0040% was made the upper limit.

Next, the reasons for limitation of the production conditions of the invention steels will be explained.

Regarding the heating temperature, it is required to be a temperature of 1050°C to 1200°C. With heating of less than 1050°C, there is a possibility of coarse inclusions having a detrimental effect on the toughness formed during the solidification remaining without being melted. Further, if heating at a high temperature, there is a possibility of precipitates formed by controlling the cooling rate during casting ending up being remelted. If based on the above, as the heating temperature for ending the phase transformation, 1200°C or less is sufficient. Coarsening of the crystal grains considered to occur at this time can be prevented in advance. Due to the above, the heating temperature was limited to 1050°C to 1200°C. It is preferably 1050°C to 1150°C.

It is necessary to end the hot rolling at 870°C or more. As the reason, when rolling at less than 870°C, the rolling is performed at the recrystallization temperature and pre-recrystallization temperature of austenite and the material quality will become unstable due to the variation in austenite grain size or the rolling is performed completely at the pre-recrystallization region and the austenite grain size is refined to 50 μm or less, so the solid solution B for segregation at the austenite grain boundaries is liable to become insufficient and as a result the quenchability will drop and the required strength will no longer be able to be obtained. For this reason, the hot rolling is ended at 870°C or more. Preferably, the hot rolling is ended at 880°C or more.

After 10 seconds to 90 seconds from the end of hot rolling, the steel slab has to be cooled from 840°C or more temperature by a 5°C/s or more cooling rate down to 200°C. If less than 10 seconds, the B does not sufficiently disperse to the austenite grain boundaries, while if over 90 seconds, the B bonds with the N in the steel, so the quenchability drops and the required strength can no longer be obtained. Further, if starting cooling at less than 840°C, this is disadvantageous from the viewpoint of the quenchability. There is a possibility that the required strength cannot be obtained. Further, with a cooling rate of less than 5°C/s, the uniform lower bainite structure or uniform martensite structure required for obtaining the required strength cannot be uniformly obtained. Further, if stopping the cooling at over a 200°C temperature, the lower bainite structure or lower structure at the martensite structure (packets, blocks, etc.) become coarser, so strength and toughness becomes difficult to secure. For the above reasons, the invention is limited to cooling the steel slab from a 840°C or more temperature by a 5°C/s or more cooling rate down to 200°C after 10 seconds to 90 seconds after finishing the hot rolling. Preferably, the cooling is performed from 860°C or more temperature.

After finishing hot rolling the steel slab and cooling it, the slat has to be tempered at a 450°C to 650°C temperature for 20 minutes to 60 minutes. When tempering, the higher the tempering temperature, the greater the drop in strength. If exceeding 650°C, this becomes remarkable, so the required strength can no longer be obtained. Further, with less than 450°C tempering, the toughness improving effect cannot be sufficiently obtained. On the other hand, if the tempering time is less than 20 minutes, the toughness improving effect is not sufficiently obtained. With tempering over 60 minutes, there is no remarkable change in material quality. Along with the increase in heat treatment time, the cost rises and a drop in productivity is invited. For the above reasons, the invention is limited to tempering at 450°C to 650°C of temperature for 20 minutes to 60 minutes after finishing the hot rolling of the steel slab and cooling it.

Examples

Next, examples of the present invention will be explained.

Steel slabs having the chemical compositions of Table 1 were hot rolled and tempered under the conditions shown in Table 2 and Table 3 to form steel plates, then were tested for evaluation of the mechanical properties. For the tensile test pieces, JIS No. 4 test pieces were taken from the 1/4 and 1/2 locations of plate thickness of the steel plates and were evaluated for YS (0.2% yield strength), TS, and El. The base material toughness was evaluated by taking JIS 2 mm V-notch test pieces from locations of 1/4 to 1/2 of the plate thickness of the different steel plates, running Charpy impact tests at -40°C, and obtaining the impact absorption energy values. Further, the HAZ toughness was evaluated by heat cycle tests correspond to a welding heat input of 5 kJ/mm and testing the obtained steel materials by a -40°C Charpy impact test to obtain the impact absorption energy values. Note that, the base material impact test energy value is preferably an average value of 100J or more and the HAZ impact test energy value is preferably an average value of 50J or more.

Table 4 and Table 5 show mechanical properties of the different steels all together. The Steels 1 to 25a show steel plates of examples of the present invention. As clear from Tables 1, 2, and 3, these steel plates satisfy the different requirements of the chemical compositions and production conditions. As shown in Table 4, it is learned that the base material characteristics and the HAZ toughness are excellent. Further, if in the prescribed range, it is learned that even if adding Ca and REM, good mechanical characteristics can be obtained.

On the other hand, the Steels 1 to 25b, as clear from Tables 1, 2, and 3, satisfy the chemical compositions, but are outside the present invention in production conditions. These steels differ from the invention, as shown in Table 4, in their reheating temperatures (Steel 5b, Steel 18b, and Steel 20b), rolling end temperatures (Steel 8b, Steel 11b, and Steel 22b), elapsed times from rolling end to cooling start (Steel 1b, Steel 10b, Steel 15b, and Steel 24b), cooling start temperatures (Steel 2b, Steel 12b, and Steel 13b), cooling rates (Steel 7b, Steel 9b, Steel 14b, and Steel 23b), cooling stop temperatures (Steel 3b, Steel 19b, and Steel 21b), tempering temperatures (Steel 4b, Steel 6b, and Steel 25b), tempering times (Steel 16b and Steel 17b), so the strengths or HAZ low temperature toughnesses are inferior.

Further, the Steels 26 to 45, as clear from Table 1, show comparative examples with chemical compositions outside the present invention. These steels, as shown in Table 5, differ from the inventions in the conditions of the amount of C (Steel 39), the amount of Si (Steel 37), the amount of Mn (Steel 31), the amount of Cu (Steel 27), the amount of Ni (Steel 33), the amount of Cr (Steel 41), the amount of Mo (Steel 26), the amount of Nb (Steel 29, Steel 43), the amount of V (Steel 30), the amount of Ti (Steel 34, Steel 44), the amount of Al (Steel 36, Steel 45), the amount of B (Steel 35), the amount of N (Steel 40), the BNPs (Steel 28, Steel 42), the amount of Ca

(Steel 32), and the amount of REM (Steel 38), so their mechanical properties, in particular the low temperature toughness (base metal and HAZ), are inferior.

Table 1

		Chemical compositions(mass%)																	
		C	Si	Mn	P	S	Cu	Ni	Cr	Mo	Nb	V	Ti	Al	B	N	BNP	Ca	REM	Ceq
INV. STEEL	1	0.09	0.10	0.65	0.007	0.002	0.48	1.00	0.35	0.26	0.002	0.035	0.001	0.056	0.0013	0.0030	2.1	0	0	0.43
	2	0.11	0.24	0.94	0.009	0.001	0.18	0.82	0.43	0.32	0.001	0.037	0.001	0.064	0.0011	0.0028	2.3	0	0	0.49
	3	0.08	0.22	0.86	0.006	0.002	0.22	0.69	0.40	0.50	0.001	0.038	0.002	0.055	0.0009	0.0022	1.8	0	0	0.47
	4	0.09	0.23	0.83	0.008	0.002	0.21	0.74	0.32	0.35	0.003	0.007	0.001	0.061	0.0011	0.0033	2.7	0	0	0.43
	5	0.09	0.18	0.92	0.008	0.003	0.18	0.72	0.36	0.34	0.002	0.040	0.001	0.058	0.0010	0.0034	3.1	0.0016	0	0.45
	6	0.10	0.21	1.97	0.007	0.002	0.13	0.25	0.41	0.32	0.002	0.031	0.001	0.066	0.0009	0.0024	2.3	0	0	0.61
	7	0.08	0.19	0.86	0.009	0.001	0.24	0.65	0.38	0.29	0.001	0.030	0.001	0.059	0.0028	0.0047	1.6	0	0	0.42
	8	0.09	0.15	0.94	0.007	0.002	0.18	0.85	0.33	0.31	0.002	0.037	0.002	0.062	0.0014	0.0058	3.7	0	0	0.45
	9	0.06	0.20	1.19	0.006	0.001	0.22	0.77	0.36	0.38	0.001	0.035	0.001	0.065	0.0010	0.0035	3.2	0	0	0.48
	10	0.09	0.23	0.79	0.009	0.002	0.24	0.79	0.31	0.31	0.001	0.041	0.001	0.064	0.0013	0.0031	2.2	0	0.0033	0.42
	11	0.10	0.19	0.82	0.010	0.001	0.21	0.81	0.49	0.05	0.001	0.032	0.002	0.057	0.0010	0.0033	2.7	0	0	0.42
	12	0.10	0.22	0.61	0.008	0.002	0.16	0.83	0.44	0.29	0.002	0.033	0.001	0.063	0.0011	0.0029	2.4	0	0	0.42
	13	0.08	0.22	0.95	0.007	0.003	0.23	0.76	0.39	0.31	0.001	0.036	0.002	0.096	0.0009	0.0038	3.6	0	0	0.45
	14	0.15	0.19	0.83	0.009	0.002	0.18	0.84	0.43	0.28	0.002	0.038	0.001	0.062	0.0011	0.0032	2.6	0	0	0.51
	15	0.09	0.15	0.86	0.008	0.001	0.21	0.82	0.46	0.33	0.001	0.032	0.001	0.064	0.0005	0.0022	3.8	0	0	0.47
	16	0.08	0.12	0.93	0.007	0.003	0.25	0.76	0.37	0.27	0.001	0.059	0.001	0.059	0.0010	0.0034	3.1	0	0	0.44
	17	0.07	0.16	1.86	0.009	0.002	0.11	0.12	0.34	0.36	0.002	0.031	0.001	0.063	0.0012	0.0032	2.4	0	0	0.54
	18	0.11	0.23	0.78	0.010	0.002	0.15	0.79	0.46	0.32	0.002	0.034	0.001	0.028	0.0013	0.0033	2.3	0	0	0.47
	19	0.09	0.27	0.83	0.006	0.003	0.22	0.83	0.06	0.48	0.002	0.030	0.001	0.061	0.0012	0.0035	2.7	0	0	0.41
	20	0.08	0.21	0.88	0.007	0.002	0.22	0.81	0.41	0.31	0.002	0.035	0.002	0.058	0.0010	0.0034	2.8	0.0034	0	0.45
	21	0.09	0.14	0.91	0.009	0.001	0.17	0.78	0.38	0.39	0.002	0.033	0.001	0.062	0.0011	0.0031	2.6	0	0.0018	0.47
	22	0.08	0.33	0.82	0.006	0.002	0.23	0.87	0.43	0.28	0.004	0.037	0.001	0.064	0.0010	0.0030	2.7	0	0	0.44
	23	0.08	0.22	0.81	0.006	0.002	0.25	1.48	0.34	0.27	0.001	0.038	0.001	0.062	0.0011	0.0032	2.6	0	0	0.46
	24	0.09	0.20	0.83	0.007	0.002	0.22	0.72	0.79	0.26	0.002	0.040	0.001	0.068	0.0012	0.0035	2.7	0	0	0.51
	25	0.08	0.18	0.78	0.006	0.001	0.18	0.67	0.32	0.58	0.001	0.036	0.001	0.063	0.0011	0.0028	2.3	0	0	0.45
COMP. STEEL	26	0.08	0.23	0.91	0.006	0.002	0.25	0.78	0.32	0.62	0.002	0.033	0.001	0.059	0.0009	0.0033	3.3	0	0	0.49
	27	0.07	0.24	0.83	0.007	0.003	0.51	0.84	0.38	0.27	0.002	0.038	0.001	0.063	0.0011	0.0031	2.6	0	0	0.44
	28	0.07	0.28	0.86	0.006	0.001	0.23	0.82	0.29	0.31	0.001	0.042	0.001	0.061	0.0012	0.0051	4.0	0	0	0.41
	29	0.09	0.25	0.87	0.010	0.002	0.21	0.79	0.34	0.32	0.005	0.035	0.002	0.056	0.0011	0.0029	2.1	0	0	0.44
	30	0.10	0.23	0.93	0.006	0.002	0.24	0.86	0.35	0.28	0.001	0.066	0.001	0.063	0.0010	0.0035	3.2	0	0	0.47
	31	0.10	0.24	2.07	0.007	0.002	0.19	0.77	0.37	0.31	0.001	0.036	0.002	0.058	0.0011	0.0033	2.5	0	0	0.65
	32	0.09	0.23	0.92	0.008	0.003	0.26	0.83	0.31	0.25	0.001	0.032	0.001	0.064	0.0013	0.0030	2.1	0.0044	0	0.43
	33	0.11	0.19	0.89	0.009	0.002	0.21	1.52	0.37	0.33	0.002	0.044	0.001	0.063	0.0011	0.0034	2.8	0	0	0.52
	34	0.09	0.31	0.85	0.008	0.002	0.22	0.87	0.36	0.31	0.002	0.032	0.004	0.061	0.0010	0.0031	1.9	0	0	0.44
	35	0.08	0.22	0.91	0.006	0.003	0.24	0.95	0.44	0.26	0.001	0.033	0.001	0.057	0.0035	0.0033	0.9	0	0	0.46
	36	0.11	0.27	0.86	0.007	0.002	0.18	0.92	0.37	0.37	0.002	0.039	0.002	0.108	0.0008	0.0036	3.8	0	0	0.48
	37	0.10	0.37	0.92	0.008	0.001	0.21	0.98	0.34	0.32	0.001	0.041	0.001	0.062	0.0009	0.0033	3.3	0	0	0.47
	38	0.09	0.18	0.85	0.009	0.003	0.23	0.79	0.42	0.29	0.001	0.035	0.001	0.057	0.0012	0.0034	2.6	0	0.0051	0.45
	39	0.16	0.21	0.83	0.008	0.002	0.24	0.84	0.37	0.27	0.002	0.042	0.001	0.064	0.0011	0.0035	2.9	0	0	0.51
	40	0.08	0.20	0.87	0.009	0.002	0.19	0.86	0.36	0.32	0.001	0.036	0.001	0.059	0.0016	0.0064	3.8	0	0	0.44
	41	0.09	0.24	0.92	0.010	0.003	0.25	0.91	0.85	0.31	0.002	0.038	0.001	0.055	0.0010	0.0028	2.5	0	0	0.56
	42	0.10	0.21	0.86	0.006	0.002	0.22	0.88	0.36	0.34	0.002	0.043	0.001	0.063	0.0013	0.0022	1.5	0	0	0.47
	43	0.09	0.26	0.94	0.007	0.003	0.23	0.78	0.43	0.28	0.008	0.036	0.001	0.063	0.0012	0.0034	2.6	0	0	0.46
	44	0.08	0.22	0.91	0.007	0.003	0.18	0.93	0.39	0.33	0.001	0.039	0.008	0.061	0.0010	0.0050	2.7	0	0	0.46
	45	0.08	0.25	0.88	0.006	0.002	0.22	0.89	0.37	0.32	0.002	0.038	0.001	0.018	0.0012	0.0036	2.8	0	0	0.45

Table 2

Steel		Plate thick. (mm)	Production condition								
			Reheat temp. (°C)	Rolling end temp. (°C)	Elapsed time from rolling to cooling start (s)	Cooling start temp. (°C)	Cooling rate (°C/s)	Cooling stop temp. (°C)	Tempering temp. (°C)	Tempering time ((min)	
1	a	30	1100	895	33	863	15	187	620	30	Inv. ex.
	b		1100	891	8	881	15	176	620	30	Comp. ex.
2	a	50	1130	889	45	875	12	194	640	20	Inv. ex.
	b		1130	876	84	837	12	185	640	20	Comp. ex.
3	a	40	1150	886	36	869	11	186	600	20	Inv. ex.
	b		1150	884	38	866	11	221	600	20	Comp. ex.
4	a	35	1050	893	31	865	16	156	620	30	Inv. ex.
	b		1050	891	30	864	16	166	680	30	Comp. ex.
5	a	45	1130	884	43	871	10	164	640	40	Inv. ex.
	b		1000	885	44	869	10	153	640	40	Comp. ex.
6	a	50	1200	890	87	874	6	178	620	30	Inv. ex.
	b		1200	892	49	883	6	168	400	30	Comp. ex.
7	a	35	1080	896	38	861	15	162	640	20	Inv. ex.
	b		1080	893	35	862	3	171	640	20	Comp. ex.
8	a	30	1100	899	37	864	17	191	650	30	Inv. ex.
	b		1100	862	15	841	17	167	650	30	Comp. ex.
9	a	50	1130	886	51	876	9	187	640	30	Inv. ex.
	b		1130	884	53	875	2	191	640	30	Comp. ex.
10	a	40	1100	887	44	868	12	183	600	20	Inv. ex.
	b		1100	885	96	841	12	172	600	20	Comp. ex.
11	a	35	1150	883	39	862	14	154	620	30	Inv. ex.
	b		1150	863	38	840	14	161	620	30	Comp. ex.
12	a	40	1080	884	46	872	9	156	640	40	Inv. ex.
	b		1080	872	81	829	9	153	640	40	Comp. ex.
13	a	35	1100	894	41	859	12	136	640	30	Inv. ex.
	b		1100	874	76	833	12	152	640	30	Comp. ex.
14	a	40	1150	890	43	869	14	185	640	20	Inv. ex.
	b		1150	890	40	867	4	172	640	20	Comp. ex.
15	a	30	1200	901	34	863	13	176	620	30	Inv. ex.
	b		1200	926	113	870	13	183	620	30	Comp. ex.
16	a	35	1130	896	33	866	10	192	620	30	Inv. ex.
	b		1130	893	36	865	10	177	620	90	Comp. ex.
17	a	40	1100	888	41	873	12	168	600	20	Inv. ex.
	b		1100	889	40	870	12	156	600	5	Comp. ex.
18	a	50	1100	879	52	868	11	173	640	30	Inv. ex.
	b		1250	882	55	865	11	179	640	30	Comp. ex.
19	a	40	1130	883	40	870	10	188	620	40	Inv. ex.
	b		1130	880	43	869	10	233	620	40	Comp. ex.
20	a	35	1150	895	36	864	14	183	620	20	Inv. ex.
	b		960	889	33	859	14	166	620	20	Comp. ex.
21	a	30	1100	899	33	861	13	153	470	60	Inv. ex.
	b		1100	903	37	862	13	209	620	30	Comp. ex.
22	a	30	1080	896	35	860	9	159	620	20	Inv. ex.
	b		1080	867	20	842	9	169	620	20	Comp. ex.
23	a	50	1150	876	51	861	10	156	620	20	Inv. ex.
	b		1150	875	48	863	3	161	620	20	Comp. ex.
24	a	80	1130	884	42	871	9	174	620	30	Inv. ex.
	b		1130	880	95	866	9	169	620	30	Comp. ex.
25	a	100	1100	900	46	896	7	163	620	30	Inv. ex.
	b		1100	902	49	899	7	159	690	30	Comp. ex.

Table 3

Steel	Plate thick. (mm)	Production condition								
		Reheat temp. (°C)	Rolling end temp. (°C)	Elapsed time from rolling to cooling start (s)	Cooling start temp. (°C)	Cooling rate (°C/s)	Cooling stop temp. (°C)	Tempering temp. (°C)	Tempering time (min)	
26	40	1130	886	41	869	11	196	620	30	Comp. ex.
27	35	1100	890	36	864	14	186	600	30	Comp. ex.
28	30	1150	891	35	862	15	191	620	20	Comp. ex.
29	30	1050	887	32	861	14	156	620	40	Comp. ex.
30	35	1080	893	37	865	12	178	620	20	Comp. ex.
31	50	1200	881	48	874	9	187	640	20	Comp. ex.
32	40	1200	885	44	868	12	153	620	30	Comp. ex.
33	45	1150	882	43	871	9	161	620	40	Comp. ex.
34	30	1150	886	36	863	17	173	640	30	Comp. ex.
35	35	1130	889	37	864	13	193	600	20	Comp. ex.
36	50	1150	879	47	873	11	184	640	20	Comp. ex.
37	45	1100	886	41	869	11	165	640	40	Comp. ex.
38	35	1100	887	35	861	14	154	620	20	Comp. ex.
39	45	1200	883	45	870	13	197	620	30	Comp. ex.
40	30	1050	883	32	863	13	181	620	20	Comp. ex.
41	30	1080	886	36	862	12	159	640	20	Comp. ex.
42	35	1130	888	38	866	16	177	620	30	Comp. ex.
43	40	1150	884	43	868	10	163	640	20	Comp. ex.
44	45	1150	886	42	871	9	189	620	30	Comp. ex.
45	100	1130	897	55	894	7	162	620	30	Comp. ex.

Table 4

Steel		Base material characteristics								Simulated HAZ characteristic (heat cycle test)		
		1/4t				1/2t						
		Strength			Toughness	Strength			Toughness	Weld heat input	Toughness	
		YS (MPa)	TS (MPa)	EL (%)	vE-40(J) (Av)	YS (MPa)	TS (MPa)	EL (%)	vE-40(J) (Av)	(heat cycle test) (kJ/mm)	vE-40(J) (Av)	
1	a	738	784	21	221	749	781	20	209	5	116	Inv. ex.
	b	713	750	20	94	677	713	21	89	5	112	Comp. ex.
2	a	841	883	22	223	799	839	21	206	5	130	Inv. ex.
	b	677	720	21	90	643	684	22	86	5	126	Comp. ex.
3	a	759	802	20	217	741	783	22	202	5	119	Inv. ex.
	b	714	776	20	97	678	737	21	92	5	115	Comp. ex.
4	a	738	783	21	221	725	781	22	208	5	116	Inv. ex.
	b	653	718	20	90	621	682	21	85	5	112	Comp. ex.
5	a	749	789	22	235	726	782	23	216	5	117	Inv. ex.
	b	714	752	21	94	679	714	21	89	5	112	Comp. ex.
6	a	821	876	19	191	780	832	22	175	5	130	Inv. ex.
	b	876	903	17	90	832	858	22	86	5	135	Comp. ex.
7	a	736	786	21	221	727	781	21	214	5	117	Inv. ex.
	b	719	749	19	94	683	712	22	89	5	112	Comp. ex.
8	a	756	803	22	238	736	789	23	221	5	119	Inv. ex.
	b	747	786	20	98	709	747	22	93	5	117	Comp. ex.
9	a	742	786	21	223	723	782	20	207	5	117	Inv. ex.
	b	708	745	19	93	672	708	21	88	5	111	Comp. ex.
10	a	734	783	20	210	721	781	21	204	5	117	Inv. ex.
	b	716	762	20	95	680	724	20	90	5	114	Comp. ex.
11	a	732	782	20	209	726	781	21	200	5	116	Inv. ex.
	b	679	715	18	89	645	679	22	85	5	111	Comp. ex.
12	a	741	785	21	222	719	782	22	209	5	117	Inv. ex.
	b	711	741	20	93	676	704	21	88	5	111	Comp. ex.
13	a	735	783	22	231	726	781	20	207	5	116	Inv. ex.
	b	715	753	21	94	680	715	21	89	5	112	Comp. ex.
14	a	951	994	18	197	903	944	23	169	5	147	Inv. ex.
	b	868	914	20	91	825	868	22	87	5	135	Comp. ex.
15	a	758	806	21	227	736	789	21	203	5	120	Inv. ex.
	b	661	703	20	88	628	668	20	83	5	116	Comp. ex.
16	a	724	781	22	228	716	780	21	215	5	116	Inv. ex.
	b	682	726	21	91	648	690	20	86	5	112	Comp. ex.
17	a	805	851	21	242	765	808	23	233	5	126	Inv. ex.
	b	828	845	20	94	787	803	21	89	5	126	Comp. ex.
18	a	809	849	22	254	703	781	22	137	5	126	Inv. ex.
	b	802	862	21	96	762	819	21	91	5	128	Comp. ex.
19	a	748	787	20	214	725	782	20	207	5	117	Inv. ex.
	b	717	763	20	95	681	725	21	91	5	114	Comp. ex.
20	a	731	784	20	209	721	781	23	198	5	117	Inv. ex.
	b	666	701	21	88	633	666	22	83	5	111	Comp. ex.
21	a	868	916	21	228	825	870	20	206	5	135	Inv. ex.
	b	852	888	19	89	810	844	21	84	5	132	Comp. ex.
22	a	734	783	22	231	719	781	20	205	5	116	Inv. ex.
	b	688	724	21	91	653	688	21	86	5	111	Comp. ex.
23	a	799	837	20	228	759	795	20	217	5	124	Inv. ex.
	b	721	766	21	96	685	728	22	91	5	114	Comp. ex.
24	a	769	801	21	231	745	790	21	222	5	119	Inv. ex.
	b	743	771	22	96	706	732	21	92	5	115	Comp. ex.
25	a	753	787	20	215	722	782	21	205	5	117	Inv. ex.
	b	707	756	21	95	672	718	20	90	5	112	Comp. ex.

Table 5

Steel	Base material characteristics								Simulated HAZ characteristic (heat cycle test)		
	1/4t				1/2t						
	Strength			Toughness	Strength			Toughness	Weld heat input	Toughness	
	YS (MPa)	TS (MPa)	EL (%)	VE-40(J) (Av)	YS (MPa)	TS (MPa)	EL (%)	VE-40(J) (Av84)	(heat cycle (kJ/mm)	vE-40(J) (Av)	
26	772	816	18	96	723	775	19	96	5	34	Comp. ex.
27	715	757	20	99	679	719	18	84	5	27	Comp. ex.
28	683	727	21	99	649	691	20	89	5	24	Comp. ex.
29	757	805	18	94	719	765	20	99	5	34	Comp. ex.
30	804	851	22	98	764	808	21	89	5	28	Comp. ex.
31	815	850	21	95	774	808	20	86	5	29	Comp. ex.
32	745	787	11	57	708	748	19	93	5	40	Comp. ex.
33	848	893	20	94	806	848	20	90	5	33	Comp. ex.
34	764	812	20	85	726	771	20	81	5	30	Comp. ex.
35	760	803	21	89	722	763	21	84	5	27	Comp. ex.
36	836	879	19	88	795	835	20	88	5	35	Comp. ex.
37	818	862	20	91	777	819	18	78	5	32	Comp. ex.
38	750	794	12	62	713	754	19	93	5	47	Comp. ex.
39	985	1036	18	99	936	984	18	94	5	46	Comp. ex.
40	724	770	19	95	688	723	21	99	5	29	Comp. ex.
41	803	853	21	94	763	810	20	85	5	30	Comp. ex.
42	802	849	20	89	762	807	18	76	5	31	Comp. ex.
43	775	819	18	96	736	778	19	96	5	34	Comp. ex.
44	732	770	20	81	695	732	21	81	5	27	Comp. ex.
45	664	707	19	70	631	672	21	74	5	26	Comp. ex.

Industrial Applicability

According to the present invention, the remarkable effects are exhibited that it is possible to produce high strength steel plate provided with both base material low temperature toughness and HAZ low temperature toughness which is Nb-free and Ti-free, has a 780 MPa class strength, and has excellent low temperature toughnesses of the base material and HAZ, that is, a low temperature toughness vE-40 of the base material of 100J or more and a low temperature toughness vE-40 of the of HAZ of 50J or more and it is possible to apply this to thick-gauge steel plate for offshore structures, penstocks, etc.

CLAIMS

1. A method of production of 780 MPa class high strength steel plate excellent in low temperature toughness characterized by heating a steel slab of chemical compositions containing, by mass%,

C: 0.06 to 0.15%,
Si: 0.05 to 0.35%,
Mn: 0.60 to 2.00%,
P: 0.015% or less,
S: 0.015% or less,
Cu: 0.1 to 0.5%,
Ni: 0.1 to 1.5%,
Cr: 0.05 to 0.8%,
Mo: 0.05 to 0.6%,
Nb: less than 0.005%,
V: 0.005 to 0.060%,
Ti: less than 0.003%,
Al: 0.02 to 0.10%,
B: 0.0005 to 0.003%, and
N: 0.002 to 0.006%,

having a balance of iron and unavoidable impurities, and

having a BNP defined by

BNP=(N-(14/48)Ti)/B

of over 1.5 to less than 4.0,

to 1050°C to 1200°C in temperature, hot rolling ending at 870°C or more, waiting for 10 seconds to 90 seconds, then cooling from 840°C or more in temperature by a 5°C/s or more cooling rate to 200°C, then tempering at 450°C to 650°C in temperature for 20 minutes to 60 minutes.

2. A method of production of 780 MPa class high strength steel plate excellent in low temperature toughness as set forth in claim 1, characterized in that said steel slab further contains, by mass%, one or more of

Ca: 0.0035% or less and

REM: 0.0040% or less.