US 20110259481A1

(19) **United States**

(12) **Patent Application Publication**

Hong et al.

(10) **Pub. No.: US 2011/0259481 A1**

(43) **Pub. Date: Oct. 27, 2011**

(54) HIGH STRENGTH STEEL PLATE FOR NUCLEAR REACTOR CONTAINMENT VESSEL AND METHOD OF MANUFACTURING THE SAME

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(21) Appl. No.: **13/141,733**

(22) PCT Filed: **Dec. 21, 2009**

(86) PCT No.: **PCT/KR09/07647**

§ 371 (c)(1),
(2), (4) Date: **Jun. 23, 2011**

(30) **Foreign Application Priority Data**

Dec. 26, 2008 (KR) 10-2008-0134885

Publication Classification

(51) **Int. Cl.**
C22C 38/44 (2006.01)

(52) **U.S. Cl.** **148/564**; 148/330

(57) **ABSTRACT**

There is provided a high strength steel plate including, by weight: 0.03% to 0.20% C, 0.15% to 0.55% Si, 0.9% to 1.5% Mn, 0.001% to 0.05% Al, 0.030% or less P, 0.030% or less S, 0.30% or less Cr, 0.2% or less Mo, 0.6% or less Ni, 0.07% or less V, 0.04% or less Nb, 5 ppm to 50 ppm Ca, 0.005% to 0.025% Ti, 0.0020% to 0.0060% N, 0.0005% to 0.0020% B, the balance of F and unavoidable impurities. The steel plate may be formed of tempered martensite, and conditions for cooling and recrystallization controlled rolling are optimized so as to control an average grain size of a microstructure and an aspect ratio of structure grains. Accordingly, a superior high-strength steel plate that can be used for an atomic plant, for example, an atomic plant rated at IOOOMW or more by having a tensile strength of at least 650 MPa and an impact toughness of at least 200 J at −5O ° C., and a method of manufacturing the same can be provided.

HIGH STRENGTH STEEL PLATE FOR NUCLEAR REACTOR CONTAINMENT VESSEL AND METHOD OF MANUFACTURING THE SAME

TECHNICAL FIELD

[0001] The present invention relates to a high strength steel plate having high tensile strength and impact toughness, and more particularly, to a high strength steel plate ensuring sufficient tensile strength and impact toughness for a nuclear reactor containment vessel, and a method of manufacturing the same.

BACKGROUND ART

[0002] Fossil fuels deposits such as those of coal and oil are gradually being depleted worldwide. Due to this global energy depletion, the importance of nuclear energy is currently drawing attention. In actuality, nuclear energy is being increasingly utilized throughout the world.

[0003] In order to achieve stable energy production, it is essential that an atomic plant be equipped with facilities and members for ensuring the safety of the atomic plant. If these measures are not in place, catastrophic events might occur when an accident happens in the atomic plant due to a variety of reasons such as natural disasters. This may cause severe damage to the environment or costs.

[0004] Various materials are used for the structures and facilities of an atomic plant according to their type, usage and safety properties. Notably, a nuclear reactor containment vessel utilizes steel. Here, A516-70 steel produced by a normalizing process is currently in common use.

[0005] However, this commonly used A516-70 steel has insufficient tensile strength (about 500 Mpa) to ensure the atomic plant s safety, and this limits the usable range thereof. A material having low tensile strength is insufficient to resist internal pressure and thus may pose a significant risk to safety.

[0006] In order to enhance tensile strength, a large amount of high-priced alloy elements may be added or a steel may be subjected to a separate thermal treatment. However, the above methods entail an increase in manufacturing costs and may cause other additional limitations. Therefore, a demand has arisen for a material that maintains existing characteristics while having a sufficient tensile strength of about 650 MPa for use in an atomic plant, for example, for a nuclear reactor containment vessel in a 1000 MW high-power nuclear power unit.

DISCLOSURE OF INVENTION

Technical Problem

[0007] An aspect of the present invention provides a high strength steel plate which is usable for atomic plants rated at 1000 MW or more by having higher tensile strength than steel for a nuclear reactor containment vessel used in an atomic plant according to the related art, and a method of manufacturing the same.

Solution to Problem

[0008] According to an aspect of the present invention, there is provided a high strength steel plate including, by weight %: 0.03% to 0.20% C, 0.15% to 0.55% Si, 0.9% to 1.5% Mn, 0.001% to 0.05% Al, 0.030% or less P, 0.030% or less S, 0.30% or less Cr, 0.2% or less Mo, 0.6% or less Ni, 0.07% or less V, 0.04% or less Nb, 5 ppm to 50 ppm Ca, 0.005% to 0.025% Ti, 0.0020% to 0.0060% N, 0.0005% to 0.0020% B, the balance of Fe and unavoidable impurities, wherein relations of $Cu+Ni+Cr+Mo \leqq 1.5\%$, $Cr+Mo \leqq 0.4\%$, $V+Nb \leqq 0.1\%$, and $Ca/S \leqq 1.0$ are satisfied. In this case, the steel plate may have a microstructure including a tempered martensite structure, and an average grain size of the microstructure is 30 μm or less. The microstructure may have a grain aspect ratio (longer axis/shorter axis) ranging from 1.1 to 2.5.

[0009] According to another aspect of the present invention, there is provided a method of manufacturing a high strength steel plate, the method including: reheating a steel slab at 1050° C. to 1250° C., the steel slab having a composition as described above; controlled-rolling the reheated steel slab in a recrystallization region at Tnr° C. to Tnr+100° C.; terminating the rolling at 870° C. to 950° C.; performing an austenization thermal treatment on the rolled steel plate at 870° C. to 950° C. for a duration of 1.3*t+(10 to 30 minutes) and then rapidly cooling the steel plate; and tempering the cooled steel slab at 650° C. to 700° C. The controlled-rolling of the reheated steel slab may be performed with a rolling reduction of at least 10% for each rolling pass and with a cumulative rolling reduction ranging from 50% to 90%. In the controlled-rolling of the reheated steel slab, a grain aspect ratio (longer axis/shorter axis) of a retained austenite structure may be controlled to a range of 1.1 to 2.5.

Advantageous Effects of Invention

[0010] According to the present invention, there can be provided a superior high strength steel plate that has a tensile strength of 650 MPa or more and an charpy impact toughness energy of 200 J or more at −50° C. and thus can be used for a nuclear reactor containment vessel in an atomic plant rated at 1000 MW or more, and a method of manufacturing the same.

BEST MODE FOR CARRYING OUT THE INVENTION

[0011] The present invention relates to a steel plate that has a tempered martensite structure, and realizes a tensile strength of about 650 MPa by using controlled rolling in a recrystallization region (i.e., recrystallization controlled rolling) whereby grains are refined and a grain aspect ratio is controlled.

[0012] Hereinafter, the contents of elements according to the present invention will be described in detail. In the following description, the sign % refers to the percent by weight.

[0013] Carbon (C) content ranges from 0.03% to 0.20%.

[0014] According to the present invention, C is an element for ensuring strength, and the content thereof is limited to the range of 0.03% to 0.20%. C content of less than 0.03% may undesirably degrade the strength of a matrix phase. In contrast, C content exceeding 0.20% impairs toughness and welding properties inadequately for an atomic plant.

[0015] Silicon (Si) content ranges from 0.15% to 0.55%.

[0016] Si is an alloy element effective for deoxidizing, solid-solution strengthening, and impact transition temperature increasing. To attain its effect sufficiently, Si needs to be added at 0.15% or more. However, Si content exceeding 0.55% impairs welding properties and causes an oxide film to be excessively formed on the surface of a steel plate. Therefore, Si content ranges from 0.15% to 0.55%, preferably from 0.15% to 0.40%.

[0017] Manganese (Mn) content ranges from 0.9% to 1.5%.

[0018] When added in an excessive amount, Mn forms MnS, an elongated nonmetallic inclusion, with sulfur (S), and thus deteriorates in elongation at a room temperature as well as low temperature toughness. Therefore, according to the present invention, Mn content is controlled to 1.5% or less. However, regarding the composition characteristics of the present invention, Mn content of less than 0.9% does not ensure sufficient strength. Therefore, Mn content is limited to the range of 0.9% to 1.5%.

[0019] Aluminum (Al) content ranges from 0.001% to 0.05%.

[0020] Al serves as a strong deoxidizer along with Si in a steelmaking process. To attain its effect sufficiently, Al needs to be added at 0.001% or more. However, Al content exceeding 0.05% saturates its effects and increases manufacturing costs. Therefore, Al content is limited to the range of 0.001% to 0.05%.

[0021] Phosphor (P) content is 0.030% or less.

[0022] P is an element that impairs low temperature toughness. Therefore, P may be added in as small an amount as possible. However, removing P excessively in the steelmaking process requires significantly high costs. Thus, P is added at levels of up to 0.030%.

[0023] Sulfur (S) content is 0.030% or less.

[0024] Like P, S is an element that adversely affects low temperature toughness. However, removing S in the steelmaking process requires excessive costs as in the case of P. Thus, S may be added at levels of up to 0.030%.

[0025] Chrome (Cr) content is greater than 0% to 0.30%.

[0026] Cr is an alloy element that enhances strength but is undesirably expensive. Cr, when added at greater than 0.30%, increases manufacturing costs. Therefore, Cr is added at levels of up to 0.30%.

[0027] Molybdenum (Mo) content is greater than 0% to 0.2%.

[0028] Like Cr, Mo is an alloy element effective for enhancing strength, and is known for preventing crack generation caused by sulfide. However, considering that Mo is a high-priced element, it is desirable to add Mo at levels of up to 0.2% taking economical aspects into consideration.

[0029] Nickel (Ni) content is greater than 0% to 0.6%.

[0030] Ni is an element effective for enhancing low temperature toughness. Ni is also a high-priced element and thus increases manufacturing costs when added excessively. Therefore, Ni is added at levels of up to 0.6% in the present invention.

[0031] Vanadium (V) content is greater than 0 to 0.07%.

[0032] V is an element effective for enhancing strength like Cr, Mo or the like, but it is expensive. Therefore, V is added at levels of up to 0.07%.

[0033] Niobium (Nb) content is greater than 0% to 0.04%.

[0034] Nb is solved in austenite to thereby enhance the hardenability of austenite, and is precipitated as carbonitride (Nb(C,N)) matching with a matrix. Thus, Nb serves as an essential element for attaining a tensile strength of at least 650 MPa pursued by the present invention. However, Nb, when added in an excessive amount, appears as coarse precipitates in the process of continuous casting, and acts as a hydrogen-induced cracking (HIC) site. Therefore, Nb content is limited to 0.04% or less.

[0035] Calcium (Ca) content ranges from 5 ppm to 50 ppm.

[0036] Ca is generated as CaS and thus serves to suppress the nonmetallic inclusion of MnS.

[0037] To attain this effect, Ca is added in an amount of 5 ppm or more according to the present invention. However, Ca, when added excessively, reacts with oxygen (O) contained in steel and thus generates CaO, a nonmetallic inclusion adversely affecting physical properties. Therefore, the upper limit of the Ca content is limited to 50 ppm.

[0038] Titanium (Ti) content ranges from 0.005% to 0.025%.

[0039] The proper Ti content may be somewhat varied according to the N content. When the added amount of Ti is small relative to the amount of N, TiN is generated in a reduced amount, thereby adversely affecting grain refinement. In contrast, when Ti is added excessively, TiN becomes coarse during a heating process and this may deteriorates the grain-growth suppression effect. Therefore, Ti content is limited to the range of 0.005% to 0.025% in due consideration of typical N content ranging from 20 ppm to 60 ppm.

[0040] Nitrogen (N) content ranges from 0.0020% to 0.0060% (20 ppm to 60 ppm).

[0041] N is known for enhancing the toughness of a base material and the impact toughness of a heat affected zone (HAZ) by forming TiN precipitates with Ti and thus rendering grains finer. In this regard, according to the present invention, N is an element that needs to be essentially added for grain refinement. Therefore, N content is limited to the range of 0.0020% to 0.0060% in consideration of Ti content. N content exceeding 0.0060% may excessively increase the amount of TiN being generated, and impair low temperature toughness.

[0042] Boron (B) content ranges from 0.0005% to 0.0020%.

[0043] B is an alloy element effective for achieving high strength by increasing hardenability even in small amount. According to the present invention, B serves as an important element in ensuring sufficient tensile strength. Accordingly, B needs to be added at 0.0005% or more in order to ensure high tensile strength, however, B content exceeding 0.0020% saturates its effects. Therefore, B is added in the range of 0.0005% to 0.0020%.

[0044] $\mathrm{Cu+Ni+Cr+Mo} \leqq 1.5\%$

[0045] $\mathrm{Cr} \leqq \mathrm{Mo} \leqq 0.4\%$

[0046] $\mathrm{V+Nb} \leqq 0.1\%$

[0047] $\mathrm{Ca/S} \leqq 1.0$

[0048] The respective relations of 'Cu+Ni+Cr+Mo', 'Cr+Mo' and 'V+Nb' are associated with measures defined by the basic standard (ASTM A20) regarding a steel for a pressure vessel. According to this standard, the total content of Cu, Ni, Cr and Mo (i.e., Cu+Ni+Cr+Mo) is limited to 1.5% or less, the total content of Cr and Mo (i.e., Cr+Mo) is limited to 0.4% or less, and the total content of V and Nb (i.e., V+Nb) is limited to 0.1% or less. Here, an alloy element that is not included in the present invention, such as copper (Cu) may be calculated as zero.

[0049] The ratio of Ca/S is a required composition ratio for spherodizing the MnS inclusion and thus enhancing resistance to HIC. The Ca/S ratio exceeding 1.0 does not ensure the above effect. Therefore, the Ca/S ratio is controlled to 1.0 or less.

[0050] Hereinafter, the microstructure of the steel plate according to the present invention will be described in detail.

[0051] Microstructure: Tempered Martensite Structure

[0052] In order to ensure sufficient strength, the present invention employs a martensite structure, generated using rapid cooling in a manufacturing process. The martensite structure significantly enhances tensile strength, and the use of this martensite structure is contributive to manufacturing a 650 MPa class steel plate pursued by the present invention.

[0053] However, martensite is known as basically having high brittleness. Since high residual stress exists, the martensite may be easily broken by external shock. The above properties of the martensite make it unsuitable for a nuclear reactor containment vessel. For this reason, the microstructure is formed into a tempered martensite structure by using a tempering process by which the residual stress is reduced and the strength of the martensite is enhanced, such that a tensile strength of 650 MPa level and an impact toughness of at least 200 J at −50° C. can be attained.

[0054] Grain aspect ratio: $1.1 \leqq$ longer axis/shorter axis $\leqq 2.5$.

[0055] The aspect ratios of the grains of the microstructure need to be controlled by using controlled-rolling in a recrystallization region. According to the present invention, the ratio of the longer axis/shorter axis is controlled to be 1.1 to 2.5. The grain aspect ratio is controlled such that high impact toughness-strength is attained. A grain aspect ratio less than 1.1 does not ensure sufficiently fine grains, whereas a grain aspect ratio greater than 2.5 may impair impact toughness.

[0056] When the grain aspect ratio is less than 1.1, a grain shape becomes rounded and this may bring about a reduction in surface energy and a failure to ensure sufficient strength and toughness. In contrast, the grain aspect ratio exceeding 2.5 undesirably increases a rolling load in forming grains.

[0057] Hereafter, conditions for each process of a method of manufacturing a steel plate according to the present invention will be described in detail.

[0058] A steel plate, according to the present invention, is produced through a series of processes of reheating-cooling-thermally treating a steel slab. In this case, in order to form the tempered martensite structure according to the present invention, crucial manufacturing conditions need to be met in the respective processes of cooling including rapid cooling, thermal treatment including tempering, and controlled-rolling in a recrystallization region for controlling the grains of a retained austenite structure.

[0059] Reheating Temperature: 1050° C. to 1250° C.

[0060] According to the present invention, a slab having the above-described composition is reheated at a reheating temperature ranging from 1050° C. to 1250° C. A reheating temperature lower than 1050° C. makes it difficult to solve solute elements. In contrast, a reheating temperature exceeding 1250° C. causes austenite grains to become excessively coarse and thus impairs the physical properties of a steel plate.

[0061] Controlled-Rolling in a Recrystallization Region: at a Temperature of Tnr° C. to Tnr+100° C., and with a Cumulative Rolling Reduction Ranging from 50% and 90% Based on a Rolling Reduction of at Least 10% for Each Rolling Pass

[0062] In order to perform this rolling process, the reheated steel slab is subjected to hot rolling within a temperature range greater than a temperature of a non-recrystallization region. 'Tnr', which refers to the temperature of the non-recrystallization region may be calculated by known Equation 1 below. Here, the unit for each alloy element is expressed by wt % in the equation.

$$\mathrm{Tnr}(^\circ\,\mathrm{C.}) = 887 - 464\times\mathrm{C} + 890\times\mathrm{Ti} + 363\times\mathrm{Al} - 357\times\mathrm{Si} + (6445\times\mathrm{Nb} - 644\times\mathrm{Nb}^{1/2}) + (732\times\mathrm{V} - 230\times\mathrm{V}^{1/2}) \qquad \text{(Equation 1)}$$

[0063] In order to acquire sufficient strength, an average grain size of retrained austenite needs to be refined to a size of 30 μm or less in the controlled-rolling process. An average grain size of retained austenite exceeding 30 μm fails to attain sufficient product strength and toughness, and to satisfy the safety level high enough for a nuclear reactor containment vessel. Therefore, the rolling is carried out within the temperature range of Tnr° C. to Tnr+100° C. according to the present invention.

[0064] In this case, the rolling on a rolling section is carried out by applying a rolling reduction of at least 10% to each rolling pass so that a final cumulative rolling reduction ranges from 50% to 90%. The rolling reduction is to control the average size of the microstructure and the grain aspect ratio (longer axis/shorter axis) to 30 μm or less and to 1.1 to 2.5, respectively. Thus, the cumulative rolling reduction less than 50% does not ensure the above effects. In contrast, the cumulative rolling reduction exceeding 90% increases the load of a rolling mill and this may cause defects in the process.

[0065] Cooling: an Austenization Thermal Treatment at 870° C. to 950° C. for a Duration of 1.3*t+(10 to 30 Minutes), and a Subsequent Rapid Cooling Process

[0066] This cooling process is a crucial step in forming the tempered martensite structure.

[0067] Conditions for the cooling process needs to be strictly controlled in order to attain a microstructure composition for ensuring a tensile strength of at least 650 MPa and an impact toughness of at least 200 J at −50° C.

[0068] To this end, the austenization thermal treatment is performed at 870° C. to 950° C. for a duration of 1.3*t+(10 to 30 minutes). Here, t denotes the thickness (mm) of a steel. The austenization thermal treatment is a heating process for making a structure into austenite so as to generate a martensite structure through a subsequent rapid-cooling process. The temperature of the thermal treatment lower than 870° C. makes it difficult to re-solve soluble elements and thus does not ensure strength sufficiently. In contrast, the temperature of the thermal treatment higher than 950° C. may grow grains into coarse grains, thereby impairing low temperature toughness.

[0069] Furthermore, the duration of the autenization thermal treatment is in the range of 1.3*t+(10 to 30 minutes) for which heating is performed and the heated temperature is maintained. Thermal treatment performed for a shorter duration slows down the implementation of the austenization effect because of insufficient heating, and does not ensure structure uniformity. In contrast, thermal treatment performed for a longer duration delays product manufacturing processes and thus degrades productivity. For reference, for the autenization thermal treatment, the duration of the heating may be set to 1.3t, and the duration for which the heated temperature, when reaching a target temperature, is maintained may be set to 10 to 30 minutes.

[0070] The austenized steel plate is subjected to the rapid cooling process, preferably to a water-cooling process, so that the microstructure is transformed into a martensite structure. According to the present invention, conditions for the rapid cooling process are not specifically limited, and any rapid cooling process, such as water cooling, is applicable to the present invention.

[0071] Tempering: at 650° C. to 700° C. for a Duration of 1.9*t+(10 to 30 Minutes)

[0072] According to the present invention, the tempering is performed in order to remove the residual stress of the generated martensite structure, thereby obtaining a tempered martensite structure. In this case, the tempering is performed at a temperature of 650° C. to 700° C.

[0073] A tempering temperature lower than 650° C. makes it difficult to precipitate carbide. In contrast, a tempering temperature exceeding 700° C. may impair steel strength. Therefore, the temperature condition of the tempering needs to be properly controlled.

[0074] In order to attain effects sufficiently, the tempering process is performed for a duration of 1.9*t+(10 to 30 minutes) where t refers to the thickness of a steel. Here, the heating duration of the tempering process may be set to 1.9t, and the duration for which the heated temperature is maintained may be set to 10 to 30 minutes.

Mode for the Invention

[0075] Hereinafter, the present invention will be described in greater detail by way of example.

Example

[0076] Slabs formed of inventive materials and comparative materials having alloy elements noted in Table 1 below were manufactured.

[0077] The respective slabs having the compositions of the inventive materials and the comparative materials noted in Table 1 were heated and subjected to controlled-rolling in a recrystallization region under conditions noted in Table 2 below. The levels of strength and low temperature toughness were evaluated after the controlled rolling, the thermal treatment and the like performed under the conditions noted in Table 2. The results are shown in Table 2 below. Here, the low temperature toughness noted in Table 2 was evaluated in terms of Charpy impact energy value obtained by conducting a Charpy impact test on samples having V notches at −50° C.

TABLE 1

	C	Mn	Si	P	S	Al	Ni	Cr	Mo	V	Nb	B	Ti	N	Ca
Inventive material a	0.06	1.35	0.35	0.008	0.0013	0.03	0.05	0.03	0.15	0.003	0.013	0.0015	0.013	0.0028	0.0018
Inventive material b	0.007	1.40	0.34	0.010	0.0014	0.02	0.15	0.05	0.10	0.005	0.012	0.0012	0.012	0.0035	0.0021
Comparative material c	0.17	1.05	0.28	0.010	0.0017	0.014	0.18	0.15	0.08	0.010	0.010	—	—	0.0032	0.0025
Comparative material d	0.14	1.15	0.29	0.012	0.0014	0.019	0.15	0.20	0.15	0.009	0.012	—	—	0.0034	0.0023

TABLE 2

	Thickness(mm)	Slab heating T(° C.)	CRR(%)	Grain aspect ratio	Rapid cooling T(° C.)	Tempering T(° C.)	YS(MPa)	TS(MPa)	Toughness(J)	Note
Inventive material a	13	1200	60	1.73	900	680	634	689	334	Inventive steel
	25	1180	75	1.95	930	670	641	691	324	Inventive steel
	45	1120	55	1.25	910	670	628	684	313	Inventive steel
	50	1120	70	1.95	910	670	621	675	339	Inventive steel
	25	1180	95	2.80	910	670	645	700	175	Low impact toughness
	50	1180	98	2.95	910	670	642	695	158	Low impact toughness
Inventive material b	30	1100	80	2.15	910	670	642	690	324	Inventive steel
	60	1100	75	2.00	930	675	648	682	318	Inventive steel
	80	1100	60	1.65	900	675	634	680	334	Inventive steel
	30	1100	45	1.09	910	670	625	670	182	Low impact toughness
	60	1100	95	2.75	910	670	645	693	160	Low impcat toughness
Comparative material c	20	1200	20	1.01	900	—	370	539	186	Comparative steel
	25	1150	30	1.03	900	—	365	530	175	Comparative steel
Comparative material d	50	1100	40	1.06	900	—	358	520	190	Comparative steel

(In table 2, T: temperature, CRR: cumulative rolling reduction)

[0078] In Table 2 above, the grain aspect ratio denotes the longer axis/shorter axis of a grain, the rapid cooling temperature of the comparative materials denote a normalizing temperature, and the impact toughness denotes impact toughness in a T direction (i.e., a direction perpendicular to a rolling direction).

[0079] According to the results shown in Table 2 above, even if a steel plate is manufactured by using an inventive material, a failure to control the aspect ratio in the controlled rolling in a recrystallization region may impair impact toughness, and thus physical properties desired by the present invention cannot be attained. Furthermore, it can be seen that the comparative materials c and d are not effective for grain refinement due to the fundamental absence of B and Ti in their compositions. For this reason, the comparative materials c and d does not allow for the formation of a microstructure sufficient to attain desired strength and toughness, and thus fail to ensure proper physical properties. Therefore, all the conditions of the present invention need to be satisfied in order to meet sufficient strength-toughness conditions and thus attain adequate physical properties for a nuclear reactor containment vessel.

1. A high strength steel plate comprising, by weight: 0.03% to 0.20% C, 0.15% to 0.55% Si, 0.9% to 1.5% Mn, 0.001% to 0.05% Al, 0.030% or less P, 0.030% or less S, 0.30% or less Cr, 0.2% or less Mo, 0.6% or less Ni, 0.07% or less V, 0.04% or less Nb, 5 ppm to 50 ppm Ca, 0.005% to 0.025% Ti, 0.0020% to 0.0060% N, 0.0005% to 0.0020% B, the balance of F and unavoidable impurities,

wherein relations of Cu+Ni+Cr+Mo≦1.5%, Cr+Mo≦0.4%, V+Nb≦0.1%, and Ca/S≦1.0 are satisfied.

2. The high strength steel plate of claim **1**, wherein the steel plate has a microstructure including a martensite structure.

3. The high strength steel plate of claim **2**, wherein the microstructure has a grain aspect ratio (longer axis/shorter axis) ranging from 1.1 to 2.5.

4. The high strength steel plate of claim **1**, wherein the steel plate has a tensile strength of at least 650 MPa, and an impact toughness of at least 200 J (charpy impact energy) at −50° C.

5. A method of manufacturing a high strength steel plate, the method comprising:

reheating a steel slab at 1050° C. to 1250° C., the steel slab comprising, by weight: 0.03% to 0.20% C, 0.15% to 0.55% Si, 0.9% to 1.5% Mn, 0.001% to 0.05% Al, 0.030% or less P, 0.030% or less S, 0.30% or less Cr, 0.2% or less Mo, 0.6% or less Ni, 0.07% or less V, 0.04% or less Nb, 5 ppm to 50 ppm Ca, 0.005% to 0.025% Ti, 0.0020% to 0.0060% N, 0.0005% to 0.0020% B, the balance of F and unavoidable impurities, wherein relations of Cu+Ni+Cr+Mo≦1.5%, Cr+Mo≦0.4%, V+Nb≦0.1%, and Ca/S≦1.0 are satisfied;

controlled-rolling the reheated steel slab in a recrystallization region at Tnr° C. to Tnr+100° C.;

performing an austenization thermal treatment on the rolled steel plate at 870° C. to 950° C. for a duration of 1.3*t+(10 to 30 minutes) and then rapidly cooling the steel plate; and

tempering the cooled steel plate at 650° C. to 700° C.

6. The method of claim **5**, wherein the controlled-rolling of the reheated steel slab is performed with a rolling reduction of at least 10% for each rolling pass and with a cumulative rolling reduction ranging from 50% to 90%.

7. The method of claim **5**, wherein, in the controlled-rolling of the reheated steel slab, a grain aspect ratio (longer axis/shorter axis) of a microstructure is controlled to a range of 1.1 to 2.5.

8. The method of claim **5**, wherein the tempering of the cooled steel slab is performed for a duration of 1.9*t+(10 to 30 minutes).

9. The high strength steel plate of claim **2**, wherein the steel plate has a tensile strength of at least 650 MPa, and an impact toughness of at least 200 J (charpy impact energy) at −50° C.

10. The high strength steel plate of claim **3**, wherein the steel plate has a tensile strength of at least 650 MPa, and an impact toughness of at least 200 J (charpy impact energy) at −50° C.

11. The method of claim **6**, wherein, in the controlled-rolling of the reheated steel slab, a grain aspect ratio (longer axis/shorter axis) of a microstructure is controlled to a range of 1.1 to 2.5.

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