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(54) HIGH-HEAT-INPUT-WELDING LOW-TEMPERATURE-RESISTANT CORROSION-RESISTANT STEEL FOR CARGO OIL TANKS AND MANUFACTURING METHOD THEREFOR

(57) The present disclosure provides a low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding and a manufacturing method therefor. The low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding includes, by weight in percent, 0.04%-0.13% C, 0.10%-0.40% Si, 0.60%-1.30% Mn, 0.005%-0.012% P, S≤0.006%, 0.01%-0.05% Al, 0.03%-0.15% Sn, 0.005%-0.020% Nb, 0.005%-0.025% Ti, 0.15%-0.40% Ni, 0.15%-0.50% Cu, 0.10%-0.25% Cr, 0.007%-0.024% Ca and the balance Fe and inevitable impurities. The corrosion-resistant steel provided by the present disclosure is mainly designed for the upper deck and inner bottom plate of a storage and transportation tank of a polar route oil tanker, and the steel has excellent low-temperature toughness and can be welded with large heat input.

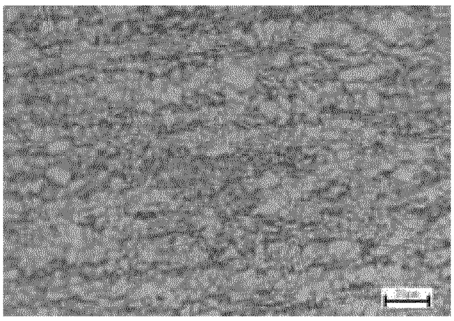

FIG 1

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Description

TECHNICAL FIELD

[0001] The present disclosure relates to the technical field of low-alloy steel for ships, in particular to low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding and a manufacturing method therefor.

BACKGROUND ART

[0002] The development in economy and society stimulates continuous increasing of demand for and consumption of crude oil, and promotes rapid growth of crude oil transportation. Apart from this, climate warming makes transportation along the Arctic routes feasible, and oil tankers through the Northern Sea Route of the Arctic routes has increased significantly. During crude oil storage and transportation, inner bottom plate of cargo oil tanks (COT) as the main storage and transportation container will be covered with a layer of deposited oil film containing sludge, high-concentration Cl^- brine and H_2S, which will cause severe local pitting corrosion with a maximum depth of 10 mm, and further a great potential safety hazard during the operation of crude oil tankers. Oil tankers sailing along the Arctic routes are required to bear the low temperature environment, and structural steel of its cargo oil tanks needs to have excellent comprehensive mechanical properties such as desirable weldability, low temperature toughness and corrosion resistance.

[0003] As required compulsorily by the International Maritime Organization (IMO) in 2012, cargo oil tanks shall be coated for protection or made of corrosion-resistant steel, so as to guarantee that structural steel of the cargo oil tanks can resist corrosion of high concentration chloride ions, temperature alternating and acidic gas phase media, and prevent oil leakage of the oil tankers from polluting marine environmental and endangering safety of the oil tankers. However, coating protection can only last for 5-7 years, and requires repair and repainting 3-4 times during the 25-year life cycle of the oil tankers, which not only prolongs maintenance man-hours, but also makes the operation environment harsh. In addition, out-of-service of the oil tankers due to docking repair has greatly increased their operation cost. Besides, with large-scale and efficient trends of oil tanker construction, 80% of workloads of shipbuilders during oil tanker construction come from a welding process, enhancing their demands for high-heat-input welding by using corrosion-resistant steel for the cargo oil. At present, corrosion-resistant steel suitable for the oil tankers can only satisfy the welding requirements of conventional low-heat-input no higher than 50 KJ/cm, and there are no reports on corrosion-resistant steel suitable for high-heat-input welding. In order to improve the shipbuilding efficiency, large shipyards generally introduce high-heat-input welding apparatuses of, for example, multi-wire submerged arc welding, flux copper backing (FCB), electro-gas welding, so as to efficiently construct oil tankers, and put forward pressing requirements for the corrosion-resistant steel for the oil tankers suitable for high-heat-input welding.

[0004] There are some researches on the corrosion-resistant steel for the cargo oil tanks at home and abroad currently, and some patents and literatures are accessible through searching, but the recorded contents are obviously insufficient in items of components, production methods, weldability, corrosion resistance, low-temperature toughness, etc. mentioned in technical solutions of the present disclosure.

[0005] Disclosed in related patent No. 1 with CN103290337A and entitled "Corrosion-Resistant Steel for Upper Deck of Cargo Oil Tank of Crude Oil Tanker" provides a common-strength and a high-strength corrosion-resistant steel specific to an upper deck of a cargo oil tank. Its ECL is 1.95mm, and low-temperature toughness only satisfies -20°C. Neither weldability evaluation indexes nor high-heat-input welding features are mentioned.

[0006] Disclosed in related patent No. 2 with CN103305761A and entitled "Corrosion-Resistant Steel for Inner Bottom Plate of Cargo Oil Tank of Crude Oil Tanker" provides a common-strength and a high-strength corrosion-resistant steel specific to an inner bottom plate of a cargo oil tank. Its low-temperature toughness only satisfies -20°C. Similarly, neither weldability evaluation indexes nor high-heat-input welding features are mentioned.

[0007] Disclosed in related patent No. 3 with CN103469101A and entitled "High Nb Corrosion-Resistant Steel for Bottom Plate of Cargo Oil Tank of Crude Oil Tanker" provides a high Nb composition system-contained and 32 Kg strength grade steel for inner bottom plate of cargo toil tanks. It only has quality Grade A (normal temperature), and cannot be applied at 0°C or a lower temperature.

[0008] Disclosed in related patent No. 4 with JP 4935578 and entitled "Corrosion-Resistant Steel Material for Ship" and related patent No. 5 with JP 5130828 and entitled "High-Strength Corrosion-Resistant Steel Material for Ship and Manufacturing Method Thereof" provide one kind of corrosion-resistant steel with desirable low-temperature toughness (quality grade E, -40°C). However, it has merely welding heat-input of 60 kJ/cm, and evaluation of corrosion properties of upper deck and inner bottom plate based on IMO standards are not provided.

[0009] Disclosed in related patent No.6 with CN102974661A and entitled "Straightening Process of Corrosion-Resistant Steel Plate of Cargo Oil Tank of Crude Oil Tanker" provides a straightening process of a steel plate with a thickness of 30-50 mm for a cargo oil tank, without mentioning key technologies such as material composition and manufacturing processes.

[0010] To sum up, in the prior art, there are still some shortcomings in product development of steel for the cargo oil tank of the oil tanker having comprehensive properties including corrosion resistance, low temperature resistance, high toughness, and suitability for high-heat-input welding. So, the requirements for efficient construction from shipyards and the requirements for comprehensive material properties from cargo oil tanks of crude oil tankers suitable for polar navigation with low temperature resistance and high-sulfur and high-acid oil corrosion resistance cannot be satisfied.

SUMMARY

[0011] In order to solve the above technical problems, low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding and a manufacturing method therefor are provided.

[0012] A technical solution adopted by the present invention is as follows:

[0013] Low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding, includes, by weight in percent:

[0014] 0.04%-0.13% C, 0.10%-0.40% Si, 0.60%-1.30% Mn, 0.005%-0.012% P, S≤0.006%, 0.01%-0.05% Al, 0.03%-0.15% Sn, 0.005%-0.020% Nb, 0.005%-0.025% Ti, 0.15%-0.40% Ni, 0.15%-0.50% Cu, 0.10%-0.25% Cr, 0.007%-0.024% Ca and the balance Fe and inevitable impurities.

[0015] Preferably, the low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding further includes, by weight in percent, at least one of 0.02%-0.15% Sb, 0.03%-0.10% W, 0.05%-0.15% Mo and 0.05%-0.10% RE.

[0016] Preferably, the inevitable impurities include, by weight in percent, 0.0020%-0.0060% N, H≤0.00015% and O≤0.0020%.

[0017] Preferably, the ratio Ti/N falls within 2.43-3.56.

[0018] Preferably, Ni+Cu is ≥0.35% and the ratio Ni/Cu is ≥ 0.70, and the ratio Ca/S falls within1.8-4.

[0019] Preferably, a thickness of a steel plate made of the corrosion-resistant cargo oil tank steel suitable for high-heat input welding is 8-50 mm, a pearlite volume fraction of microstructure of the corrosion-resistant steel having a yield strength 1355 MPa (36 Kg) is ≤30%, and bainite volume fractions of the corrosion-resistant steel having a yield strength of ≧370 MPa (40 Kg) and that of ≧420 MPa are ≤35%.

[0020] Action mechanisms of alloy components in the corrosion-resistant steel for an acid crude oil storage and transportation tank of the present disclosure are described in detail below with the percent symbol % representing the weight percent:

[0021] C is a necessary element for guaranteeing strength of steel and has a content of 0.04% or higher. However, when the content exceeds a certain amount, welding crack sensitivity may be improved resulting in deterioration of a welding property. In addition, increase of the C content may also increase a content of pearlite phases containing lamellar cementite in steel. In acidic environment, pearlite becomes cathode and may promote corrosion accordingly; moreover, a heat affected zone (HAZ) near a re-fusion line of a welded steel plate is prone to produce MA, thereby significantly reducing low-temperature toughness of the material, and determining an upper limit of the C content to 0.13%.

[0022] Si is a main deoxidizing component in a steelmaking process, and shall have a content of 0.10% or higher for sufficient deoxidizing effect. However, if the content of Si exceeds an upper limit, toughness of a base metal and a welded portion may be reduced, and Si in the form of a solid solution may increase a ductile-brittle transition temperature while improving a strength, so the content of Si ranges from 0.10% to 0.40%.

[0023] Mn is a necessary element to guarantee the strength and the toughness of steel. Mn combines with S to form MnS, so as to avoid hot cracks caused by FeS at a grain boundary. Besides, Mn is also a desirable deoxidizer. As a low-cost strengthening and toughening element, a too low content of Mn may not guarantee material strength. However, Mn with a content higher than 1.30% may worsen segregation of the slab and low-temperature toughness of a coarse grained heat affected zone (CGHAZ), so the Mn content should be controlled within 0.60%-1.30%.

[0024] P is an inevitable impurity element in steel and may worsen toughness and weldability of same. A research shows that when P content is higher than 0.012%, corrosivity of P under the condition of an acid gas phase medium on the upper deck decreases significantly, so as to determine an upper limit to 0.012%.

[0025] S is prone to form MnS inclusions in steel, and locations of the MnS inclusions are origins of pitting corrosion, thus reducing corrosion resistance of steel. Therefore, measures should be taken to reduce the S content in steel as much as possible. Therefore, in the present disclosure, an upper limit of the S content is determined to be 0.006%.

[0026] Al, as a deoxidizing and grain refining element, is generally added by an amount of 0.01% or more. However, Al with a too high content is prone to produce hot cracks in a slab, and a large quantity of Al_2O_3 inclusions (hard phase inclusions) are formed, which may significantly reduce toughness of steel. Therefore, the upper limit of the Al content is determined to be 0.05%.

[0027] Sn is an essential component in the present disclosure for improving corrosion resistance. Sn exists in steel in the form of solid solution, which may significantly improve electrochemical corrosion self-potential of steel, thus inhibiting corrosion of steel in acid corrosive environment. However, Sn with a content lower than 0.03% may not effectively improve corrosion resistance, and Sn with a content higher than 0.15% may be enriched in austenite grain boundaries during hot working processes such as continuous casting and rolling, and may reduce high-temperature plasticity accordingly. Therefore, the content of Sn ranges from 0.03% to 0.15%.

[0028] Ni is conducive to formation of a dense rust layer on the surface of steel when added by a proper amount, and may inhibit corrosion reaction of steel, especially when coexisting with Cu, Cr, etc. Because Ni may increase strength, reduce a critical cooling rate and delay pearlite transformation, Ni is conducive to microstructure control, grain refinement and low-temperature toughness improvement. However, under the condition of S-containing atmosphere, formation of nickel sulfide may cause red brittleness of steel, so the content of Ni should not be too high. Therefore, the content of Ni is controlled within 0.15%-0.40% in the present disclosure.

[0029] Cu may obviously improve corrosion resistance of a steel plate, especially seawater corrosion resistance, and may obviously guarantee corrosion resistance of the steel plate of the present disclosure. However, Cu with a high content is unfavorable to toughness and prone to cause steel plate embrittlement, and is controlled within 0.15%-0.50% of the present disclosure.

[0030] Cu/Ni composite addition has main action mechanisms in steel in the following two aspects: on the one hand, addition of Cu and Ni promotes formation of α-FeOOH in steel. In wet and dry alternate environment, Ni may promote formation of spinel oxides and increase a density of a rust layer; Cu may become a core of oxide crystallization in the rust layer, thus promoting formation of α-FeOOH. α-FeOOH is a relatively stable phase in the rust layer, and may hardly transform into other phases once formed, so as to avoid cracks and defects caused by volume change caused by phase transformation. On the other hand, under the condition of a certain potential in a corrosive medium, Cu may dissolve to form Cu^{2+} and form an insoluble protective film with some anions, for example, Cu_2S which effectively protects a substrate, and these insoluble salts of Cu may repair and protect cracks and holes, thus improving compactness of the continuous rust layer. Therefore, it is determined that the addition amount of Ni+Cu is ≥0.35% and the ratio of Ni/Cu is ≥0.70 in steel, so as to inhibit adverse effects of Cu on low temperature toughness.

[0031] Sb may improve corrosion resistance of steel like Sn, and is proved to effectively improve corrosion resistance of steel in acid corrosive environment. If added with Sn, Sb may further improve the corrosion resistance of steel, and is an optional added element of the present disclosure. Sb with the content higher than 0.15% may enable the corrosion resistance to be saturated and reduces thermoplasticity of steel. Therefore, the content of Sb ranges from 0.02% to 0.15%.

[0032] W is an optional added element for improving corrosion resistance in the present disclosure. W may form WO_4^{2-} ions in acidic corrosive environment to inhibit corrosion of anions such as Cl- ions, and may also form a dense layer of $FeWO_4$ to inhibit corrosion. W with the content higher than 0.10% may enable the corrosion resistance effect to be saturated, and is not conducive to weldability, so an upper addition limit is 0.10%.

[0033] Cr forms a dense Cr_2O_3 layer on a steel surface along with oxidation, and may inhibit intrusion of anions in acid corrosion environment, thus reducing enrichment of Cl^- and other anions on the steel surface, and has a desirable pitting corrosion resistance effect for a steel plate in inner bottom plate environment. However, Cr with a too-high content may increase welding crack sensitivity. With consideration of weldability and corrosion resistance, an optimum addition content of Cr ranges from 0.10% to 0.25%.

[0034] Mo may improve corrosion resistance of steel like W and Cr, and may promote formation of a dense rust layer on the surface of steel and prevent further development of corrosion. With consideration of cost and corrosion resistance, an optimum addition content of Mo ranges from 0.05% to 0.15%.

[0035] RE has a function of steel purification, and may effectively purify grain boundaries, thus improving corrosion resistance of the grain boundaries and reducing an overall corrosion rate. Besides, RE is a desirable desulfurizing and deoxidizing agent, and may improve low-temperature toughness and weldability. RE as a modifier may improve a shape, a size and distribution of inclusions, and further enhance comprehensive mechanical properties of materials. However, RE with a too-high content may increase difficulty of smelting and continuous casting, and increase manufacturing cost of products. Therefore, the content of RE in the present disclosure is controlled ranging from 0.05% to 0.10%.

[0036] Nb may effectively refine a grain size of steel and is an element added to improve strength and toughness of same. Nb with a content lower than 0.005% produces little positive effect on the strength and the toughness of steel, Nb with a content higher than 0.020% may produce MA brittle components easily during high-heat input welding, so as to reduce weldability and low-temperature toughness of steel. Therefore, the content of Nb ranges from 0.005% to 0.020%.

[0037] Ti is a component added to improve toughness of steel and welded portions. As a strong N-fixing element, Ti is prone to form TiN and therefore improves N-porosity resistance of weld metal. Ti with a content lower than 0.005% has little effect. Ti with a content higher than 0.021% is prone to form large particles of TiN and loses effect. In order to obtain low-temperature toughness of a steel plate under high heat input, it is necessary to control the ratio of Ti:N in steel within 2.43-3.56, so an addition content of Ti ranges from 0.005% to 0.021%.

[0038] Ca combines S to form CaS which may coat alumina and other inclusions, and achieve denaturation and spheroidization of the inclusions, and therefore facilitate improvement of corrosion resistance, toughness and fatigue resistance. In addition, fine dispersed CaS formed in advance may reduce the formation ratio of MnS, and CaS reacts with H_2O to dissociate alkaline OH^- ions, which may reduce an acidification degree of corrosion pits and smaller pitting corrosion sensitivity. Moreover, CaO with a fine size formed in steel may also play a role in grain refinement and material toughness improvement. In the present disclosure, it is preferable that the Ca content ranges from 0.007% to 0.024% and the ratio of Ca/S ranges from 1.8% to 4%.

[0039] N may form fine precipitates with Nb, Ti and V, play a role of strengthening and grain refinement, and improve strength and toughness of steel. However, N with a too high content may deteriorate the toughness, and the content should be controlled ranging from 0.0020% to 0.0060%.

[0040] H and O are harmful impurity elements in the present disclosure. Increase contents of H and O may lead to improvement of hydrogen-induced cracking tendency and increase of inclusions, and decrease of corrosion resistance and fatigue resistance. Therefore, in the present disclosure, H is controlled ≤0.00015% and O is controlled ≤0.0020%.

[0041] The present disclosure further discloses a method for manufacturing the low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding. The manufacturing method includes:

Smelting: performing smelting with deep desulfurized molten iron, where a weight percent of sulfur in the deep desulfurized molten iron is ≤0.002%; adding the molten iron in a converter and performing smelting, and the adjusting and adding above chemical components in the converter, such that the chemical components in the converter satisfy the weight percent of the low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding;
Refining: performing secondary refining on molten steel taken out of the converter;
Continuous casting: continuously casting the molten steel subjected to secondary refining to obtain a plate slab;
Heating: heating, for 3-5 hours, the plate slab to 1100°C-1150°C;
Rolling: rolling the heated steel slab, performing first-stage rolling to obtain an intermediate slab, and performing second-stage rolling on the intermediate slab, where an initial rolling temperature of the first-stage rolling is 950°C-1100°C, an initial rolling temperature of the second-stage rolling is 850°C-900°C, and a final rolling temperature of the second-stage rolling is 800°C-860°C; and
On-line cooling: performing on-line cooling on a rolled steel plate to 500°C-600°C at a cooling rate of 5°C/s-20°C/s to obtain the steel plate.

[0042] The initial rolling temperature of the second-stage rolling ranges from 850°C to 900°C, the final rolling temperature of the second-stage rolling ranges from 840°C to 860°C; and in the on-line cooling process, the rolled steel plate is cooled to 550°C to 600°C at the cooling rate of 5°C/s to 15°C/s. Alternatively, in the rolling process, the initial rolling temperature of the second-stage rolling ranges from 850°C to 890°C, the final rolling temperature of the second-stage rolling for a rolled steel plate ranges from 800°C to 840°C, and in the on-line cooling process, the rolled steel plate is cooled to 500°C to 560°C at the cooling rate of 7°C/s to 20°C/s.

[0043] Preferably, the manufacturing method further includes offline cooling: shearing and getting a finished product steel plate with a thickness<40 mm off a production line, and transporting same to a finished product stacking area; and stacking, for not shorter than 24 hours, to slowly cool a straightened finished steel plate with a thickness≥40 mm with an initial temperature being 250°C to 400°C, and shearing and getting the product off a production line, and transporting same to a finished product stacking area.

[0044] Preferably, in the smelting process, smelting production is performed by primary point blowing with high catch carbon.

[0045] Preferably, in the smelting process, basicity of final slag falls within 3.2-4.1, and tapping time is not shorter than 5 min.

[0046] Preferably, in the refining process, aluminum particles, silicon carbide and calcium carbide are used to adjust the slag, and the final slag after refining has basicity≥2.4. After refining, Ca treatment is performed, and wire feeding for molten steel in each furnace is 200-300 m.

[0047] Preferably, in a continuous casting process, a degree of superheat is≤25°C, secondary cooling in the continuous casting process adopts weak cooling, a casting speed of continuous cast plate slab is 0.8 m/min-1.2 m/min, and a thickness of continuous cast plate slab is 200 mm-360 mm;

[0048] Preferably, in the rolling process, the ratio of a thickness of the intermediate slab to a thickness of a finished steel plate is not less than 2.5:1, and a cumulative reduction rate of the first-stage rolling and the second-stage rolling is not less than 50%.

[0049] The steel plate formed with the steel provided by the present disclosure has a Charpy impact toughness ≧198 J at -60°C, an ECL corrosion rate (25-year extrapolated corrosion rate) ≤2.0 mm, and a fracture toughness satisfying the characteristic value δ c ≧ 0.8 mm at -10°C of crack tip opening displacement (CTOD). And after welding at 240 KJ/cm, Charpy impact toughness (AKv) of a weld joint is ≧ 170 J at -40°C.

[0050] According to the present disclosure, the corrosion-resistant steel is mainly designed for overall uniform corrosion of the upper deck and local pitting corrosion of the inner bottom plate of the storage and transportation tank of the polar route oil tanker, and the material has excellent low-temperature toughness (satisfying -60°C) and may be welded with large heat input (linear energy of 240 KJ/cm). Base metal and high-heat-input welded joint prepared by the present disclosure are subjected to mechanical performance evaluation and simulated corrosion performance evaluation in wet-dry alternate corrosion environment of top mixed gas (O_2-CO_2-SO_2-H_2S) and corrosion environment of a bottom high-acid solution (10%NaCl solution with pH=0.85) of a cargo oil tank of an actual oil tanker. Results show that comprehensive mechanical properties and corrosion resistance satisfy the requirements of International Association of Classification Societies (IACS) and IMO standards.

[0051] Compared with the prior art, the present disclosure has the following advantages:

(1) Under a chemical composition system based on a classification society specification, the present disclosure uses low C and low Mn elements, so as to reduce the corrosion sensitivity; a proper amount of Ni, Cu and Mo may be added to make up the strength and improve the corrosion resistance; fine carbonitride precipitated by Nb, Ti and V plays a role in strengthening and grain refining, so as to guarantee that the steel plate still has excellent low-temperature toughness at -60 °C. By reducing P, S, H, O contents, the N content, the size and the shape of the inclusions, segregation, etc. are strictly controlled so as to guarantee the corrosion resistance and improve the low-temperature toughness and weldability. The segregation of the continuous cast slab is less than grade 0.5, and the sum of four types of inclusions A, B, C and D is ≤ grade 2.0. By controlling cleanliness of steel and the weight, the size and the quantity of the inclusions, the strength, the toughness, the corrosion resistance and weldability of the steel of the present disclosure are guaranteed.
(2) Microstructures of polygonal ferrite+pearlite and polygonal ferrite+bainite are obtained by using the component design and manufacturing method of the present disclosure, and in addition the uniformity of the microstructures plays a desirable role in potential difference reduction and high corrosion resistance.
(3) A maximum thickness of the corrosion-resistant steel plate suitable for high-heat-input welding of the present disclosure is 50 mm, and the strength grade of the steel plate may cover 355 MPa (36 kg), 390 MPa (40 kg) and 420 MPa, and the low-temperature toughness may satisfy grade F toughness indexes, especially the excellent fracture toughness (CTOD) at a low temperature, reaching 0.8 mm or higher. When the welding heat input reaches 240 KJ/cm, the steel plate still has desirable strength and toughness, satisfying application technical requirements from the materials needed for construction of the cargo oil tank of the polar route oil tanker.
(4) The present disclosure provides the environment-friendly and long-life high-performance steel for building the cargo tank of the polar route oil tanker, such that the oil tanker does not need maintenance in the whole life cycle, and a lot of painting and maintenance operation cost may be saved.

[0052] Based on the above reasons, the present disclosure may be widely popularized in the fields including low alloy marine steel.

BRIEF DESCRIPTION OF THE DRAWINGS

[0053] In order to more clearly illustrate technical solutions in the embodiments of the present disclosure or in the prior art, a brief introduction to the accompanying drawings required for the description of the embodiments or the prior art will be provided below. Obviously, the accompanying drawings in the following description are some of the embodiments of the present disclosure, and those ordinary skilled in the art would also be able to derive other drawings from these drawings without making creative efforts.

FIG 1 is a microstructural diagram of grade 355 MPa of corrosion-resistant steel suitable for high-heat-input welding in an embodiment of the present disclosure.
FIG 2 is a microstructural diagram of grade 420 MPa of corrosion-resistant steel suitable for high-heat-input welding in an embodiment of the present disclosure.
FIG 3 is a microstructural diagram of a corrosive lower bottom plate in an embodiment of the present disclosure.
FIG 4 is an auto-focusing three-dimensional appearance analysis diagram of a corrosive lower bottom plate in an embodiment of the present disclosure.
FIG 5 is a microstructural diagram of a corrosive upper deck in an embodiment of the present disclosure.
FIG 6 is an auto-focusing three-dimensional appearance analysis diagram of a corrosive upper deck in an embodiment of the present disclosure.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0054] To make the objectives, technical solutions and advantages of embodiments of the present disclosure more obvious, the technical solutions of the present disclosure will be clearly and completely described below in conjunction with the accompanying drawings in the embodiments of the present disclosure, and obviously, the described embodiments are some, rather than all of the embodiments of the present disclosure. The following description of at least one example embodiment is merely illustrative in nature, and is in no way intended to limit the present disclosure, an application or use thereof. Based on the embodiments of the present disclosure, all other embodiments acquired by those of ordinary skill in the art without making creative efforts fall within the scope of protection of the present disclosure.

[0055] It should be noted that the terms used herein are only intended to describe specific embodiments and are not intended to limit the example embodiments of the present disclosure. As used herein, unless indicated obviously in the context, a singular form is also intended to include a plural form. In addition, it should also be understood that the terms "include" and/or "comprise" used in this specification indicate features, steps, operations, devices, components and/or their combinations.

[0056] Except as otherwise specifically set forth, the relative arrangement of components and steps, numerical expressions and numerical values set forth in these embodiments do not limit the scope of the present invention. In addition, it should be clear that, for ease of description, sizes of the various components shown in the accompanying drawings are not drawn according to actual proportional relationships. Technologies, methods, and devices known to those of ordinary skill in the relevant fields may not be discussed in detail, but where appropriate, the technologies, methods, and devices should be considered as a part of the authorization specification. In all the examples shown and discussed herein, any specific value should be interpreted as merely example rather than limiting. Therefore, other examples of the example embodiments may have different values. It should be noted that similar reference signs and letters represent similar items in the accompanying drawings below. Therefore, once an item is defined in one accompanying drawing, the item does not need to be further discussed in a subsequent accompanying drawing.

[0057] As shown in FIGs. 1-6, the present disclosure discloses a low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding. The low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding includes, by weight in percent:

[0058] 0.04%-0.13% C, 0.10%-0.40% Si, 0.60%-1.30% Mn, 0.005%-0.012% P, S≤0.006%, 0.01%-0.05% Al, 0.03%-0.15% Sn, 0.005%-0.020% Nb, 0.005%-0.025% Ti, 0.15%-0.40% Ni, 0.15%-0.50% Cu, 0.10%-0.25% Cr, 0.007%-0.024% Ca and the balance Fe and inevitable impurities.

[0059] The low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding further includes, by weight in percent, at least one of 0.02%-0.15% Sb, 0.03%-0.10% W, 0.05%-0.15% Mo and 0.05%-0.10% RE.

[0060] The inevitable impurities include, by weight in percent, 0.0020%-0.0060% N, H≤0.00015% and O≤0.0020%.

[0061] Ni+Cu is ≥0.35% and the ratio Ni/Cu is ≥ 0.70, the ratio Ti/N falls within 2.43-3.56, and the ratio Ca/S falls within 1.8-4.

[0062] A thickness of a steel plate made of the corrosion-resistant cargo oil tank steel suitable for high-heat input welding is 8-50 mm, a pearlite volume fraction of a microstructure of corrosion-resistant steel with a yield strength 1355 MPa (36 Kg) is ≤30% (see FIG 1), and bainite volume fractions of corrosion-resistant steel with a yield strength of ≧390 MPa (40 Kg) and 1420 MPa are ≤35% (see FIG 2).

[0063] The composition design and the manufacturing method of the present disclosure is use to control a microstructure and the phase ratio of corrosion-resistant steels with different strength grades. For grade 355 KPa(36 Kg) high-strength steel, a microstructure of polygonal ferrite+a small amount of pearlite (see FIG 1) is obtained, and a volume fraction of pearlite is ≤30%. For ultra-high strength steel with grades 390 MPa (40 Kg) and 420 MPa, a microstructure of acicular ferrite+a small amount of bainite is obtained (see FIG 2), a bainite volume fraction is ≤35%. In addition, grain sizes of steel plates of various steel grades and thicknesses are effectively controlled. Since a relatively single microstructure plays a desirable role in reduction of corrosion potential differences between different phases and high corrosion resistance of materials.

[0064] The element compositions of Embodiments 1 to 10 and weight percents thereof are shown in Table 1.

Table 1

C	Si	Mn	P	S	Nb	Ti	Sn	Ni	Cu	RE
0.04	0.10	1.30	0.006	0.006	0.012	0.013	0.05	0.15	0.20	/
0.05	0.36	1.10	0.009	0.0054	0.017	0.012	0.03	0.30	0.15	0.05
0.073	0.28	1.16	0.005	0.0055	0.020	0.011	0.148	0.20	0.27	/
0.13	0.40	0.60	0.010	0.0044	0.015	0.011	0.12	0.24	0.25	0.072
0.085	0.20	0.97	0.012	0.0025	0.006	0.008	0.08	0.18	0.21	/
0.10	0.33	0.68	0.010	0.0039	0.008	0.014	0.05	0.40	0.50	0.10

(continued)

C	Si	Mn	P	S	Nb	Ti	Sn	Ni	Cu	RE
0.077	0.29	0.95	0.009	0.005	0.010	0.008	0.13	0.28	0.36	/
0.092	0.37	1.25	0.006	0.0053	0.017	0.005	0.06	0.25	0.35	0.066
0.12	0.11	1.19	0.0082	0.006	0.009	0.021	0.11	0.34	0.43	/
0.086	0.26	1.07	0.011	0.004	0.014	0.011	0.14	0.28	0.40	0.097
Ni/Cu	Mo	Cr	A1	Ca	Ca/S	N	Ti/N	Sb	W	
0.75	0.12	0.10	0.048	0.024	4	0.0048	2.78	/	/	
200	/	0.17	0.015	0.011	2	0.0035	3.3	/	/	
0.74	/	0.22	0.023	0.014	2.46	0.0031	3.5	0.07	/	
0.96	/	0.15	0.010	0.010	2.18	0.0035	3.14	0.02	0.03	
0.86	/	0.25	0.022	0.010	3.92	0.003	2.83	/	0.10	
0.80	0.09	0.13	0.050	0.007	1.8	0.0058	2.43	0.098	/	
0.78	0.05	0.24	0.044	0.013	2.67	0.0032	2.5	/	0.078	
0.71	0.15	0.19	0.035	0.015	2.88	0.0020	2.64	0.148	/	
0.79	/	0.23	0.018	0.021	3.53	0.0060	3.56	0.122	0.092	
0.70	0.083	0.14	0.037	0.012	2.9	0.0033	3.27	0.056	0.065	

[0065] This embodiment further discloses a method for manufacturing the low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding. The manufacturing method includes:

[0066] Smelting: smelting is performed with deep desulfurized molten iron, where a weight percent of sulfur in the deep desulfurized molten iron is ≤0.002%; after the molten iron reaches a converter, contents of elements are adjusted in the converter to satisfy the chemical components and weight percents thereof in the above description, processes combining "double slag" dephosphorization with "slag skimming" of tapping side molten steel are used for smelting; smelting production is performed by primary point blowing with high catch carbon; basicity of final slag falls within 3.2-4.1, through effective slag retaining operation, a large amount of slag carry-over is eliminated, and tapping time is not shorter than 5 min.

[0067] Refining: refining is performed, specifically secondary refining on molten steel taken out of the converter, so as to further reduce contents of harmful impurities such as O, S and nonmetallic inclusions. In the refining process, aluminum particles, silicon carbide and calcium carbide are used to adjust the slag, and the final slag after refining has basicity ≥2.4 ("double slag" refers to final slag of smelting and refining); and after completion of the refining, Ca treatment is performed, and wire feeding for molten steel in each furnace is 200 m-300 m.

[0068] Continuous casting: continuous casting is performed on the molten steel subjected to secondary refining to obtain a plate slab; in a continuous casting process, a degree of superheat is ≤25°C, secondary cooling in the continuous casting process adopts weak cooling, a casting speed of continuous cast plate slab is 0.8 m/min-1.2 m/min, and a thickness of casted plate slab is 200 mm-360 mm.

[0069] Heating: the plate slab is heated to 1100-1150°C for 3-5 hours. This heating temperature is used because a temperature lower than 1100°C is not hot enough to completely dissolve alloying elements into austenite, and therefore may not guarantee a final rolling temperature required for hot rolling. However, when the temperature is higher than 1150°C, original austenite grains coarsen significantly, and significantly reduces the low-temperature toughness of the steel plate accordingly.

[0070] Rolling: the heated plate slab is rolled. First-stage rolling is performed on the heated plate slab to obtain an intermediate slab, and second-stage rolling first-stage rolling is performed on the intermediate slab, where an initial rolling temperature of the first-stage rolling is 950°C-1100°C, an initial rolling temperature of the second-stage rolling is 850°C-900°C, and a final rolling temperature of the second-stage rolling is 800°C-860°C. The rolling temperature is selected to satisfy the requirements of mechanical properties of corrosion-resistant steel. An austenite recrystallization temperature zone is 950°C-1100°C, and an austenite non-recrystallization temperature zone is 850°C-900°C. The ratio of a thickness of the intermediate slab to a thickness of a steel plate subjected to second-stage rolling is not less than 2.5:1, and a cumulative reduction rate of the first-stage rolling and the second-stage rolling is not less than 50%.

[0071] On-line cooling: a rolled steel plate is cooled to 500°C-600°C at a cooling rate of 5°C/s-20°C/s to obtain the steel plate.

[0072] According to the requirements of mechanical properties of the steel plate, different rolling temperatures in the non-recrystallization zone and cooling rates may be selected. For high-strength steel with a yield strength 1355 MPa (36 kg), in order to satisfy impact temperature of -60°C, preferably, the initial rolling temperature of second-stage rolling falls within 850°C-900°C, the final rolling temperature of that falls within 840°C%-860°C, a cooling manner is of multi-stage laminar cooling, and the cooling rate is controlled within 5°C-15°C/s, and the rolled steel plate is cooled to 550°C-600°C. The volume fraction of the pearlite in the microstructure of the obtained steel plate is ≤30%.

[0073] For high-strength steel with a yield strength ≧390 MPa (40 kg) and ≧420 MPa, in order to satisfy the requirements of strength and impact temperature of -60°C, preferably, the initial rolling temperature of second-stage rolling is 850°C-890°C, the final rolling temperature of that is 800°C-840°C, and then the steel plate is cooled to 500°C-560°C at a cooling rate of 7°C/s- 20°C/s. The bainite volume fraction in the microstructure of the obtained steel plate is ≤35%.

[0074] A finished product steel plate with a thickness <40 mm is sheared and gotten off a production line, and transported to a finished product stacking area. A finished steel plate with a thickness ≥40 mm is, after being straightened, stacked for not shorter than 24 hours to slowly cool with an initial temperature being 250°C-400°C,and then the finished product steel is sheared and gotten off the production line, and transported to the finished product stacking area.

[0075] The corrosion-resistant steel plate made by the above method has a thickness of 8mm-50mm, has excellent comprehensive mechanical properties, and is suitable for high-heat-input welding. The corrosion-resistant steel plate made by the above method has excellent corrosion resistance detected with a corrosion evaluation method specified by IMO and may be used without coating protection.

[0076] The process parameters of heating-rolling-cooling control in Embodiments 1 to 10 are shown in Table 2.

Table 2

Embodi ments	Steel grade	Thickne ss of plate mm	Heatin g temper ature , °C	Rolling tempera ture of first-sta ge rolling , °C	Tempera ture-hol ding thicknes s of intermed iate slab (t represen ts finished product)	Rolling temperature of second-stage rolling, °C		Initia 1 temp eratu re of wate r-coo ling/ °C	Final temp eratu re of wate r-coo ling/ °C	Cooling rate of water-cooling /°C/s
						Initial	Final			
1	355MPa	8	1100	1050	2.5t	890	860	760	595	5.0
2	355MPa	30	1120	1040	3.0t	900	850	788	568	15.0
3	355MPa	40	1135	1050	2.5t	850	840	765	550	10.6
4	390MPa	50	1110	1056	3.0t	885	840	780	560	19.8
5	390MPa	32	1140	1030	3.2t	860	800	744	525	14.0
6	390MPa	20	1100	980	3.0t	880	840	765	528	12.87
7	420MPa	8	1150	1080	2.8t	890	820	770	550	7.0
8	420MPa	36	1130	1090	2.8t	860	816	798	532	10.0
9	420MPa	44	1142	1100	2.5t	850	812	789	500	19.8
10	420MPa	28	1150	1070	3.5t	865	808	767	525	15.4

[0077] In Table 2, embodiments 1-3 relates to steel with a yield strength of 355 MPa and above, Embodiments 4-6 relates to steel with a yield strength of 390 MPa. Embodiments 6-10 relates to steel with a yield strength of 420 MPa. The final rolling temperature is different from the initial temperature of water-cooling because the temperature may naturally decrease during transportation.

[0078] Mechanical properties of Embodiments 1 to 10 are shown in Table 3.

Table 3

	Number	Plate thickness mm	Tensile properties			Impact properties		CTOD$_{-10°C}$ (δc), mm	Ageing impact AKv (-40°C) (J)	Microstr ucture proporti on (%)
			Yield strength Reh (MPa)	Tensile strength Rm (MPa)	Elongat ion after fracture A (%)	Impact temperatu re (°C)	Impact energy (1)			
Embodi ments	1	8	402	522	25.5	-60	244	0.82	132	pearlite 20%
	2	30	375	526	30	-60	329	214	182	pearlite 25%
	3	40	367	512	27.5	-60	262	1.56	156	pearlite 18%
	4	50	395	518	29.5	-60	332	1.32	175	bainite 10%
	5	32	421	538	28	-60	254	0.90	128	bainite 12%
	6	20	435	572	24.5	-60	265	0.94	206	bainite 20%
	7	8	475	590	22.5	-60	232	0.80	197	bainite 30%
	8	36	460	587	24.5	-60	198	1.35	156	bainite 25%
	9	44	453	565	25.5	-60	206	1.42	180	bainite 16%
	10	28	468	602	240	-60	214	1.25	174	bainite 35%
Ship codes	≥355			490~620	≥21	-60 (L)	≥34	≥0.40	≥34	
	≥390			510~660	≥20	-60 (L)	≥39		≥39	
	≥420			520~680	≥19	-60 (L)	≥42		≥42	

[0079] It can be seen from Table 3 that the yield strength of 355 MPa steel provided by the present disclosure falls within 367 MPa to 402 MPa, the tensile strength of that falls within 512 MPa to 526 MPa, and the elongation after fracture of that is 25.5% and above. At -60°C, impact toughness falls within 244 J to 329 J, and fracture toughness satisfies $CTOD_{-10°C}$ ≧ 0.82 mm higher than ≥ 0.40 mm specified by ship codes.

[0080] The yield strength of 390 MPa steel provided by the present disclosure falls within 395 MPa to 435 MPa, the tensile strength of that falls within 518 MPa to 572 MPa, and the elongation after fracture is 24.5% and above. At -60°C, impact toughness falls within 254 J to 332 J, and fracture toughness satisfies $CTOD_{-10°C}$ ≧ 0.90mm higher than ≥ 0.40mm specified by ship codes.

[0081] The yield strength of 420 MPa steel provided by the present disclosure falls within 435 MPa to 475 MPa, the tensile strength of that falls within 565 MPa to 602 MPa, and the elongation after fracture of that is 22.5% and above. At -60°C, impact toughness falls within 198 J to 232 J, and fracture toughness satisfies $CTOD_{-10°C}$ ≧0.80 mm far higher than ≥ 0.40 mm specified by ship regulations.

[0082] To sum up, corrosion-resistant steels of various steel grades have desirable mechanical property stability and surplus strength and toughness indexes, and may fully satisfy the material design requirements from high-toughness, high-weldability, corrosion-resistant steel for oil tankers.

[0083] Mechanical properties of the joints welded at 240KJ/cm in Embodiments 1 to 10 are shown in Table 4.

Table 4

	Number	Plate thicknes s mm	Tensile properties			Charpy impact toughness (L)		Hardness (HV)
			Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Impact temperature (°C)	Impact energy (1)	
Embodiments	1	8	/	580	24.5	-40	199	265
	2	30	/	534	27	-40	236	223
	3	40	/	521	25.5	-40	214	201
	4	50	/	520	27.5	-40	269	194
	5	32	/	556	26.5	-40	201	241
	6	20	/	567	22.5	-40	212	252
	7	8	/	624	21.5	-40	178	289
	8	36	/	608	23	-40	170	281
	9	44	/	590	22.5	-40	172	272
	10	28	/	631	21.5	-40	189	305
Ship codes		/		490~620	≥21	-40 (L)	≥34	≤350
		/		510~660	≥20	-40 (L)	≥39	
		/		520~680	≥19	-40 (L)	≥42	

[0084] It can be seen from Table 4 that, after the steel provided by the present disclosure is welded at 240 KJ/cm, the parameters of tensile strength, elongation and hardness still satisfy the ship codes, and the impact toughness of the weld joint at -40°C is ≧ 170 J, far higher than the ship codes.

[0085] For Embodiments 1-10, the corrosion rate of corrosion-resistant steel for upper deck based on IMO 289(87) standard is shown in Table 5.

Table 5

	Number	Plate thickness mm	25-year extrapolated corrosion rate (ECL/mm)			Etching step height (μm)	
			Base metal	Weld joint	IMO standard	Measured value	IMO standard
Embodiments	1	8	1.27	1.32	≤2.0	8.4	≤30

(continued)

	Number	Plate thickness mm	25-year extrapolated corrosion rate (ECL/mm)			Etching step height (μm)	
			Base metal	Weld joint	IMO standard	Measured value	IMO standard
	2	30	1.43	1.49		16.3	
	3	40	1.12	1.18		7.5	
	4	50	1.26	1.55		12.0	
	5	32	1.48	1.52		19.5	
	6	20	1.33	1.35		17.0	
	7	8	1.05	1.22		10.2	
	8	36	1.21	1.40		12.5	
	9	44	1,33	1,56		13.6	
	10	28	1.55	1.74		22.3	

[0086] It can be seen from Table 5 that the ECL corrosion rate (25-year extrapolated corrosion rate) of the steel provided by the present disclosure is ≤ 2.0 mm satisfying the standards. Furthermore, it can be intuitively seen from FIGs 5-6 that an etching step height in Embodiment 4 is 12 μm satisfying the standards undoubtedly.

[0087] For Embodiments 1-10, the corrosion rate of corrosion resistant steel for inner bottom plate based on IMO 289(87) standard is shown in Table 6.

Table 6

	Number	Plate thickness mm	average corrosion rate (mm/year)			Etching step height (μm)	
			Base metal	Weld joint	IMO standard	Measured value	IMO standard
Embodiments	1	8	0.57	0.60	≤1.0	16.8	≤30
	2	30	0.63	0.65		10.2	
	3	40	0.52	0.53		15.5	
	4	50	0.46	0.51		13.8	
	5	32	0.68	0.72		12.0	
	6	20	0.54	0.60		15.6	
	7	8	0.42	0.51		40	
	8	36	0.48	0.56		18.35	
	9	44	0.55	0.62		19.0	
	10	28	0.64	0.80		21.3	

[0088] It can be seen from Table 6 that the annual average corrosion rate of the steel provided by the present disclosure is ≤ 0.72 mm satisfying the IMO standards, and the corrosion step height further satisfies the IMO standards. It can be seen intuitively from FIGs 3-4 that the etching step height in Embodiment 7 is 4 μm, even better than a required value of the IMO standards.

[0089] To sum up, the low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding provided by the present disclosure satisfies the ship codes, has properties far higher than those in the ship codes, and has desirable corrosion resistance, excellent low-temperature toughness at -60 °C , and desirable strength and toughness even when the welding heat input reaches 240 KJ/cm, and therefore satisfies application technical requirements from the materials needed for construction of the cargo oil tank of the polar route oil tanker.

[0090] At last, it should be noted that the above various embodiments are merely intended to illustrate the technical solution of the present disclosure and not to limit the same; although the present disclosure has been described in detail with reference to the foregoing embodiments, it should be understood by those ordinary skilled in the art that the technical solutions described in the foregoing embodiments can be modified or equivalents can be substituted for some or all of the technical features thereof; and the modification or substitution does not make the essence of the corresponding technical solution deviate from the scope of the technical solution of each embodiment of the present disclosure.

Claims

1. Low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding, comprising, by weight in percent:
   0.04%-0.13% C, 0.10%-0.40% Si, 0.60%-1.30% Mn, 0.005%-0.012% P, S≤0.006%, 0.01%-0.05% Al, 0.03%-0.15% Sn, 0.005%-0.020% Nb, 0.005%-0.025% Ti, 0.15%-0.40% Ni, 0.15%-0.50% Cu, 0.10%-0.25% Cr, 0.007%-0.024% Ca and the balance Fe and inevitable impurities.

2. The low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding according to claim 1, further comprising, by weight in percent, at least one of 0.02%-0.15% Sb, 0.03%-0.10% W, 0.05%-0.15% Mo and 0.05%-0.10% RE.

3. The low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding according to claim 1, wherein the inevitable impurities comprise, by weight in percent, 0.0020%-0.0060% N, H≤0.00015% and O≤0.0020%.

4. The low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding according to claim 3, wherein the ratio Ti/N falls within 2.43-3.56.

5. The low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding according to claim 1, wherein Ni+Cu is ≥0.35% and the ratio Ni/Cu is ≥ 0.70, and the ratio Ca/S falls within 1.8-4.

6. A method for manufacturing the low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding, comprising:

   heating, for 3-5 hours, a plate slab with the components according to any one of claims 1-5 to 1100 °C to 1150°C;
   performing first-stage rolling on the heated steel slab to obtain an intermediate slab, and performing second-stage rolling on the intermediate slab, wherein an initial rolling temperature of the first-stage rolling is 950 °C to 1100 °C, an initial rolling temperature of the second-stage rolling is 850 °C to 900 °C, and a final rolling temperature of the second-stage rolling is 800 °C to 860 °C; and
   performing on-line cooling on the rolled steel plate to 500 °C to 600 °C at a cooling rate of 5°C/s-20°C/s to obtain the steel plate.

7. The method for manufacturing the low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding according to claim 6, wherein in the rolling process, the final rolling temperature of the second-stage rolling ranges from 840 °C to 860 °C; and in the on-line cooling process, the rolled steel plate is cooled to 550 °C to 600 °C at the cooling rate of 5 °C/s to 15 °C/s, and a pearlite volume fraction of the cooled steel plate is ≤ 30%.

8. The method for manufacturing the low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding according to claim 6, wherein in the rolling process, the initial rolling temperature of the second-stage rolling ranges from 850 °C to 890 °C, and the final rolling temperature of the second-stage rolling ranges from 800 °C to 840 °C; and in the on-line cooling process, the rolled steel plate is cooled to 500 °C to 560 °C at the cooling rate of 7 °C/s to 20 °C/s, and a bainite volume fraction of the cooled steel plate is ≤ 35%.

9. The method for manufacturing the low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding according to claim 6, further comprising:
   performing offline cooling: stacking, for not shorter than 24 hours, to slowly cool a straightened finished steel plate with a thickness ≥ 40 mm with an initial temperature being 250 °C to 400 °C, shearing and getting the product off a production line, and transporting same to a finished product stacking area.

10. The method for manufacturing the low-temperature-resistant and corrosion-resistant cargo oil tank steel suitable for high-heat-input welding according to claim 6, wherein
in the rolling process, the ratio of a thickness of the intermediate slab to a thickness of a finished steel plate is not less than 2.5, and a cumulative reduction rate of the first-stage rolling and the second-stage rolling is not less than 50%.

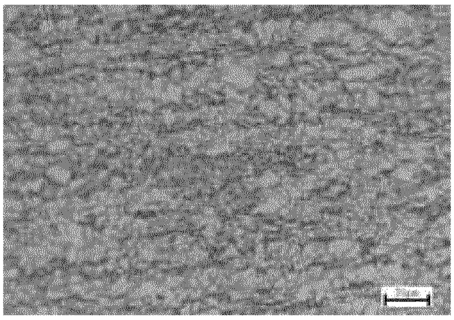


FIG 1

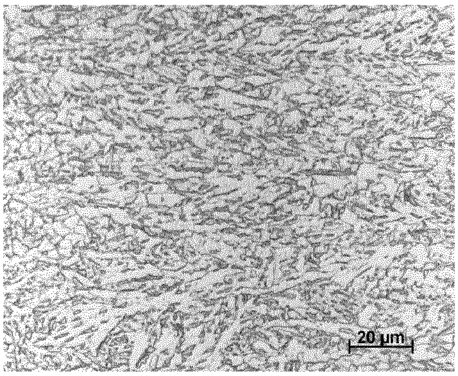


FIG 2

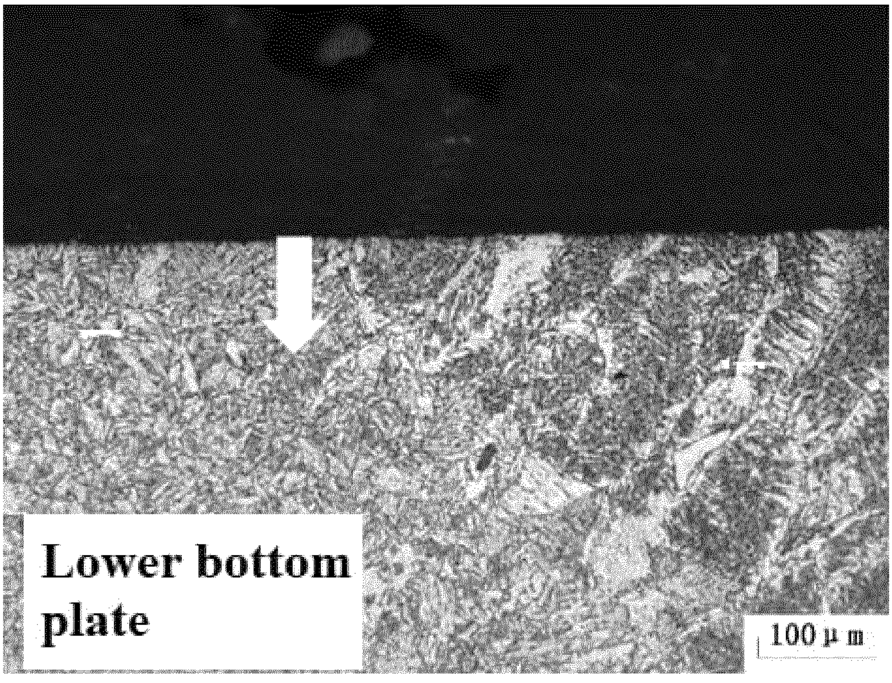
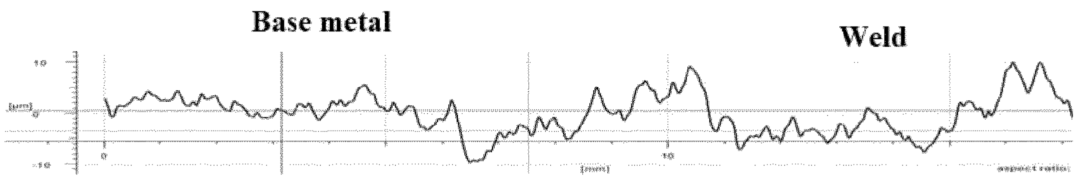


FIG 3



Step height △H=4.0 μm

FIG 4

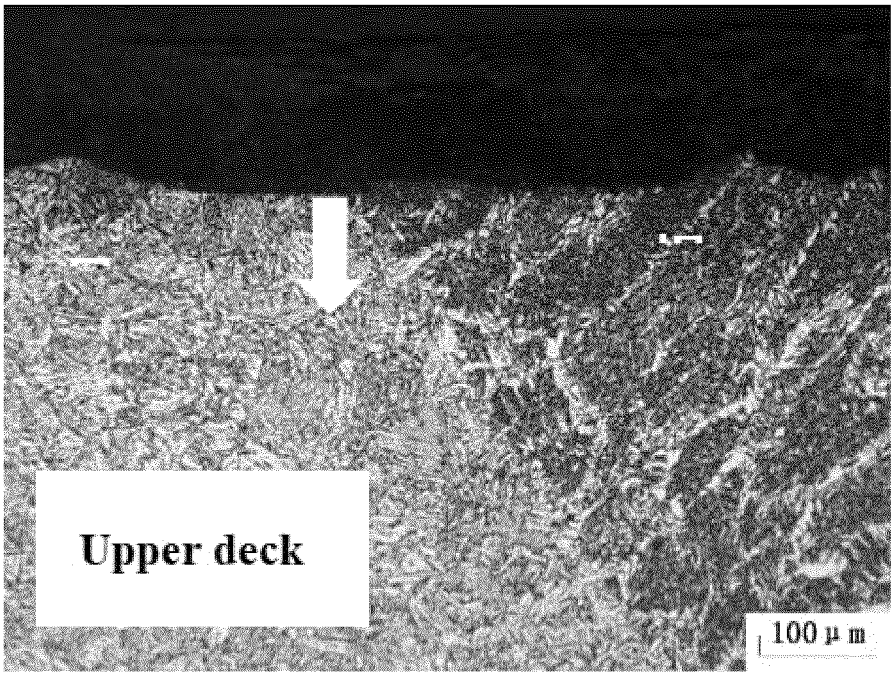
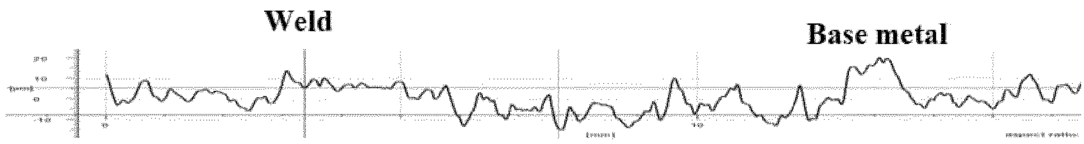


FIG 5



S Step height △H=12 μm

FIG 6

INTERNATIONAL SEARCH REPORT

International application No. **PCT/CN2021/132953**

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/42(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

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNPAT, WPI, EPODOC, CNKI: 钢, C, Si, Mn, P, S, Al, Sn, Nb, Ti, Ni, Cu, Cr, Ca, 热输入, 焊接, 加热, 轧制, 冷却, 腐蚀, steel, weld+, heat+, roll+, cool+, corrosion, heat w input

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 112899558 A (BAOSTEEL ZHANJIANG IRON AND STEEL CO., LTD.) 04 June 2021 (2021-06-04) description, paragraphs 7-81, and figure 1	1-10
X	CN 103205644 A (BAOSHAN IRON & STEEL CO., LTD.) 17 July 2013 (2013-07-17) description, paragraphs 7-78, and figure 1	1-10
X	CN 104046898 A (BAOSHAN IRON & STEEL CO., LTD.) 17 September 2014 (2014-09-17) description, paragraphs 6-73, and figure 1	1-10
X	CN 109423572 A (BAOSHAN IRON & STEEL CO., LTD.) 05 March 2019 (2019-03-05) description, paragraphs 7-81, and figure 1	1-10
A	CN 110331334 A (WUHAN UNIVERSITY OF SCIENCE AND TECHNOLOGY) 15 October 2019 (2019-10-15) entire document	1-10
A	JP 2009127076 A (SUMITOMO METAL INDUSTRIES, LTD.) 11 June 2009 (2009-06-11) entire document	1-10

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

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
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Date of the actual completion of the international search	Date of mailing of the international search report
21 July 2022	**17 August 2022**

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
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