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(54) ANTI-DELAYED CRACKING AND WEAR-RESISTANT STEEL PLATE AND MANUFACTURING METHOD THEREFOR

(57) The invention provides an erosion-corrosion resistant steel plate with delayed cracking resistance and its manufacturing method, wherein the steel plate comprises the following chemical elements in wt%: C: 0.17-0.22%, Si: 0.1-0.3%, Mn: 1.0-1.4%, P≤0.015%, S≤0.005%, Al: 0.018-0.04%, Cu: 0.15-0.60%, Ni: 0.1-0.31%, B: 0.001-0.003%, N≤0.005%, and one or both of Nb: 0.01-0.03% and Ti: 0.01-0.03%, with the balance being Fe and inevitable impurities; and the following conditions are satisfied: 5.68N≤Nb+Ti≤0.044 and Cu/Ni≤2.0. The steel plate of the present application exhibits excellent resistance to delayed cracking and is suitable for manufacturing pipelines used in areas such as land reclamation from the sea and channel dredging.

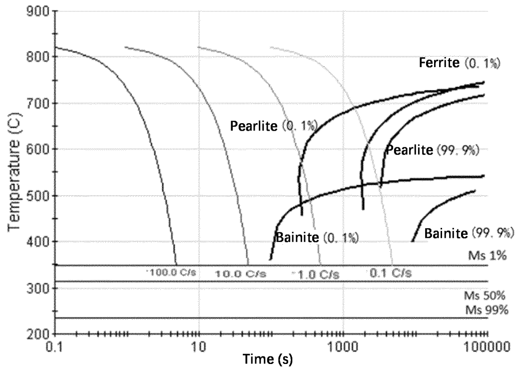

Figure 1

EP 4 520 847 A1

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Description

TECHNICAL FIELD

[0001] The present invention relates to the field of alloys, in particular to an erosion-corrosion resistant steel plate resistant to delayed cracking, suitable for slurry dredging, and its manufacturing method.

BACKGROUND

[0002] In operations such as land reclamation, channel dredging, and embankment maintenance, a large amount of solid particles like mud and gravel are transported over long distances in the form of slurry through dredging pipes. The pipe body is subjected to electrochemical corrosion from the slurry medium and wear from solid particles, as well as the interaction of both. This wear is particularly severe when the seawater slurry contains weathered rock, coral reefs, and medium-coarse sand, which cause significant erosion-corrosion to the inner wall of the pipe body. The existing dredging pipelines are mostly made of ordinary steel such as Q235B and Q345B, with a short service life under harsh working conditions, often being scrapped in less than 1 year. Due to the interaction of corrosion and wear during the failure process, the material failure caused by erosion-corrosion is much higher than the combined effects of pure corrosion and wear. Therefore, steel for dredging pipes not only requires wear resistance but also corrosion resistance to achieve good erosion-corrosion resistance. To reduce dredging costs, it is generally required to use higher strength erosion-corrosion resistant steel plates to manufacture dredging pipes, thereby increasing the service life of the pipes. Studies show that high-strength steel plates are prone to delayed cracking in corrosive dredging operations, so high strength dredging pipes made of erosion-corrosion resistant steel plates must address the delayed cracking problem.

[0003] In terms of improving the wear resistance of steel materials, many related existing technologies have already been disclosed. For example, CN103397272A discloses "Wear resistant steel plate with low crack sensitively index and high strength and its manufacturing method" and CN103103448A discloses "A low alloy high-strength and high toughness wear resistant steel plate". The two disclosures pertain to steel grades with a hardness reaching 450 HBW, the steel plates are primarily used in fields such as construction machinery and mining equipment, which show good wear resistance. However, in terms of composition design, both add a high amount of Mo alloy element on a C-Mn basis, resulting in higher alloy costs, and the steel contains a high amount of corrosion-resistant element Si, which negatively affects toughness. These patents do not take measures to control corrosion and cannot meet the performance requirement under working conditions involving both corrosion and wear.

[0004] Several foreign patents have also been filed and disclosed for wear resistance steel, primarily used in the manufacturing of construction machinery, but not relate to the area of slurry transportation involving abrasive characteristics. For example:
US5284529A discloses "Abrasion-resistant Steel", which pertains to steel grades containing up to 0.05-1.5% of Ti and 0.1-3.0% of Mo. The alloy cost is relatively high, and the maximum hardness is 420 HBW.

[0005] JP2007231321A and JP2008169443A respectively disclose "Wear Resistant Steel Sheet" and "Wear-Resistant Steel Sheet Superior in Workability and Manufacturing Method Therefor", introducing methods to improve wear resistance through carbide precipitation of Ti and W. However, the hardness of the former is generally between 396-431 HBW, while the latter is less than 300 HBW, failing to reach the 450 HBW hardness level. A large number of carbide particles in the matrix act as cathodes in erosive environments, which promotes the occurrence of electrochemical corrosion and increases material loss due to erosion. Therefore, although the steel plate exhibits good wear resistance, its resistance to erosion-corrosion is poor. These patents do not address delayed cracking.

[0006] CN101886225A discloses "A corrosion-resistant and wear-resistant steel and its manufacturing method", the patent pertains to a steel grade with a hardness of 52 HRC or more. The matrix contains up to 0.4-0.9% C and 14-16% Mn, with Mo and Cr contents both in the range of 5-10%. Additionally, it contains rare elements such as Pr, Nd, and Gd. This steel plate belongs to a high-alloy steel grade and is associated with high costs.

[0007] CN102776445A and CN108930001A respectively disclose "A bainitic wear-resistant steel pipe for slurry transportation and its manufacturing method" and "A high-hardness erosion-corrosion resistant steel plate for slurry dredging and its manufacturing method". The steel grades involved in the former are all bainitic or bainitic + acicular ferrite microstructures, which have relatively low matrix hardness and a tensile strength of only 600-800 MPa. These steel pipes are primarily used for the transport of slurries or crude oil with fine particles (tens of microns), and are not suitable for the transportation of large particle, high-density seawater slurries. The latter is a 450 HBW ultra-high strength erosion-corrosion resistant steel plate, which does not consider delayed cracking in its composition design and performance requirements. During dredging operations, the steel plate is prone to crack when subjected to impacts and hard object scratches, particularly in a corrosive environment, the steel plate may be susceptible to delayed cracking, leading to leaking or even cracking in the pipe body and affecting the dredging operation.

[0008] In dredging operations, the dredging pipeline, as an important component, faces corrosion issues both inside and outside the pipe body during use and mechanical damage such as impacts and scratches on its outer wall. For lower-strength steel plates such as Q235B, Q345B, the low yield strength allows for deformation and energy absorption to ensure safety. However, for high-strength steel plates, especially those with a yield strength exceeding 1000 MPa, the damage stress they experience is often difficult to surpass the yield strength of the steel. As a result, when subjected to such damage, the steel plate cannot deform. This leads to the initiation and propagation of cracks at the damaged locations. In corrosive environments, cracks promote hydrogen penetration and diffusion, especially due to electrochemical corrosion. The hydrogen atoms infiltrate the steel's lattice, increasing the vacancy concentration, forming microvoids, and further promoting microcrack initiation, leading to brittle cracking, i.e., delayed cracking. This significantly impacts dredging operations and reduces pipeline life, increasing costs. The higher the strength of the steel plate, the more it is affected by hydrogen penetration. Thus, even if the surface of the pipeline is undamaged, high-strength steel plates used in dredging must consider resistance to delayed cracking.

[0009] From the prior art, it is evident that the wear-resistant steel either does not consider their corrosion resistance or the issue of delayed cracking under high stress, making them unsuitable for dredging pipes.

SUMMARY

[0010] The objective of the present invention is to provide an erosion-corrosion resistant steel plate with resistance to delayed cracking and its manufacturing method, which has a yield strength of ≥1100MPa, tensile strength of ≥1300MPa, elongation of ≥12%, hardness of 450±30HBW, an impact energy at -40°C of ≥60J. The erosion-corrosion resistance of the steel plate is 2 times or more that of ordinary steel plates, and in a U-bend testing, the steel plate does not crack after being immersed in a 0.1 mol/L hydrochloric acid solution for 600 hours or more (i.e., the cracking time is 600 hours or more). The steel plate of the present application exhibits excellent delayed cracking resistance, suitable for pipeline production in land reclamation and channel dredging, with no cracking or leakage when subjected to impacts and scratches on its surface in a corrosive environment, thereby significantly improving dredging efficiency and reduces operational costs.

[0011] To achieve the above-mentioned objective, the present invention provides an erosion-corrosion resistant steel plate with excellent resistance to delayed cracking, wherein the steel plate comprises the following chemical elements in wt%: C: 0.17-0.22%, Si: 0.1-0.3%, Mn:1.0-1.4%, P≤0.015%, S≤0.005%, Al: 0.018-0.04%, Cu: 0.15-0.60%, Ni: 0.1-0.31%, B: 0.001-0.003%, N≤0.005%, and one or both of Nb: 0.01-0.03% and Ti: 0.01-0.03%, the balance of Fe and inevitable impurities.

[0012] Preferably, contents of elements N, Nb, and Ti satisfy the following inequality: 5.68N≤Nb+Ti≤0.044. In some embodiments, the lower limit for Nb+Ti in the inequality can be, for example, 6.15N, 6.37N, or 6.65N. In some embodiments, the upper limit of Nb + Ti can be, for example, 0.044, 0.04, 0.039, or 0.034. For example, contents of elements N, Nb, and Ti satisfy the following inequality: 6.65N≤Nb+Ti≤0.04.

[0013] Preferably, elements Cu and Ni satisfy the following inequality: Cu/Ni≤2.0. The lower limit of Cu/Ni is not restricted, and can be 0, 0.7, or 1.1. The upper limit of Cu/Ni is also not restricted, and can be 2, 1.9, 1.8, 1.6, or 1.5. For example, the elements Cu and Ni satisfy the following inequality: 0.7≤Cu/Ni≤2.0.

[0014] Preferably, the steel plate further comprises one or more of the following: Cr≤2.0%, W: 0.01-0.5%, Mo: 0.01-0.5%, Sb: 0.01-0.2%, REM: 0.01-0.2%, V: 0.01-0.2%, and Ca: 0.001-0.01%.

[0015] Preferably, a Cu content in the steel plate is 0.29-0.60%.

[0016] Preferably, a thickness of the steel plate is 8-20mm.

[0017] In the composition design of the steel plate in the present invention:

C is the most affordable strengthening element in steel, which can significantly improve the strength of the steel plate. However, excessive C negatively impacts the weldability, toughness, and plasticity of the steel plate. Therefore, C content is limited to 0.17-0.22% to meet performance requirements.

[0018] Si serves as a deoxidation element and a solid solution strengthening element. It is also a common corrosion-resistant element in weathering steels. Si in steel replaces Fe atoms by substitution, hindering dislocation movement and thus achieving solid solution strengthening. Si reduces the diffusion coefficient of C in ferrite, increases the activity of carbon, suppresses the formation of carbides, and inhibits the precipitation of coarse carbides at defects, thereby improving toughness. However, excessive Si promotes the graphitization of C, which is detrimental to toughness, surface quality, and weldability. Therefore, the content of Si is limited to 0.1-0.3%.

[0019] Mn is also a common strengthening element in steel, enhancing yield strength through solid solution strengthening, which reduces elongation, significantly lowers the phase transformation temperature of steel, and refines the microstructure of steel. Mn is an important strengthening and toughening element. However, excessive content of Mn increases hardenability, leading to poor weldability and deterioration of toughness of the welding heat-affected zone, as well as increased costs. Therefore, Mn content is controlled at 1.0-1.4%.

[0020] P is a main corrosion-resistant element in weathering steel, promoting the formation of a protective rust layer on the surface, effectively enhancing the atmospheric corrosion resistance. However, during erosion and corrosion, the formation of the surface rust layer accelerates the material loss due to erosion and corrosion, reducing erosion-corrosion resistance. The presence of P easily causes segregation, lowering toughness and plasticity of the steel, making the steel brittle and affecting its toughness. Therefore, the content of P in steel should be minimized. In the present invention, P content is controlled to 0.015% or less.

[0021] S can improve the yield strength of the steel, but the presence of S deteriorates the atmospheric corrosion resistance of steel, makes the steel brittle, and reduces the low-temperature toughness of the steel. Therefore, S content is controlled to 0.005% or less.

[0022] Al is usually added to steel as a deoxidizer during the steelmaking process. Trace amounts of Al are beneficial for refining grains and improving the strength and toughness of the steel. As a ferrite-forming element, excessive Al decreases steel strength and increases the brittleness of ferrite, thereby reducing toughness. Therefore, Al content is limited at 0.018-0.04%, preferably 0.02-0.04%.

[0023] Cu plays a role in solid solution and precipitation strengthening. When the content of Cu is relatively high, the steel plate exhibits a secondary hardening effect when tempered at an appropriate temperature, thereby increasing the strength of the steel plate. Cu is also one of the elements that enhance corrosion resistance. The electrochemical potential of Cu is higher than that of Fe. On one hand, adding an appropriate amount of Cu helps to increase the self-corrosion potential of the steel plate, reducing the corrosion rate. On the other hand, it promotes the densification and stabilization of the surface rust layer, thereby improving corrosion resistance. As the corrosion resistance of the steel plate improves, the evolution of hydrogen during the corrosion process is reduced, which enhances the resistance to delayed cracking. The addition of Cu inhibits the diffusion of hydrogen, reducing the sensitivity to hydrogen-induced cracking, especially when combined with Cr to jointly improve resistance to delayed cracking. To ensure the effect of Cu, its content is maintained at no less than 0.15%. However, excessive Cu causes cracks during heating and hot rolling of steel billets, deteriorating surface properties, thereby the upper limit of copper content is set to 0.60%.

[0024] Ni exists in steel in a solid solution state and does not form carbides, acting as an austenite-forming element. The addition of Ni to steel has a grain-refining effect, enhancing low-temperature impact toughness by refining grains and reducing stacking fault energy. In high-strength steel, Ni homogenizes the microstructure of steel, inhibits diffusion behavior of hydrogen, and reduces the content of irreversible hydrogen traps, thereby improving resistance to delayed cracking. Ni is also an important corrosion-resistant element, enriching in the rust layer, refining rust layer grains, and promoting the formation of the nanophase, superparamagnetic α-FeOOH in the inner rust layer. The particle size of the formed α-FeOOH is less than 15 nm, which increases the density of the inner rust layer, making it difficult for chloride ions to penetrate through the rust layer and contact the steel substrate, thereby reducing the corrosion rate. Especially Ni stabilizes the rust layer and mitigates hot working brittleness caused by Cu. Considering the effect of Cu on elevating potential and the inhibition hydrogen diffusion by Cu and Ni, the present invention takes Cu and Ni as important elements to improve resistance to delayed cracking. To achieve optimal matching effect and suppress copper brittleness, the ratio of Cu and Ni is restricted, requiring $Cu/Ni \leq 2.0$. However, since Ni is a precious element, the content of Ni is limited to 0.1-0.31%, preferably 0.1-0.30%.

[0025] B accumulates at dislocations and defects in steel, reducing grain boundary energy and suppressing ferrite transformation, thereby improving hardenability and increasing the hardness of the steel plate. In addition, trace amounts of B have a strong tendency to accumulate at the austenite grain boundaries, forming Fe_2B, which can create good coherent interfaces with austenite, reducing interface energy at grain boundaries, thus delaying ferrite nucleation and stabilizing austenite. The addition of B improves the low temperature impact toughness of steel plates after low temperature tempering, lowering the ductile to brittle transition temperature. B-containing steel tempered around 300°C has higher impact toughness than non-B-containing steel, though it is lower when tempered above 500°C. When the B content is low, it accumulates in the half-atomic planes of edge dislocations due to the hydrostatic pressure field from edge dislocations in austenite, minimizing its influence on grain boundaries, and its effect on hardenability is not significant. Therefore, the content of B is required to be 0.001% or more. However, excessive B reduces grain boundary strength, causing intergranular fracture and cleavage under stress, resulting in the "boron embrittlement" phenomenon. In addition, too much B negatively affects weldability, and the strengthening effect does not increase further while promoting grain boundary segregation, leading to embrittlement and a decrease in stamping performance. Therefore, the content of B is controlled to 0.003% or less.

[0026] N forms nitrides with Nb, V, and Ti in steel. These fine precipitates pin grain boundaries, refining austenite grains. The precipitated nitrides also provide precipitation strengthening. However, a high content of N in steel tends to combine with Al to form AlN, which significantly increases the amount of nitrides in steel. When AlN exists as a non-metallic inclusion, it disrupts the continuity of the steel matrix. Especially when Al content is high, a large amount of AlN is formed and clustered, causing greater harm and forming oxides with poor plasticity. Furthermore, a high N content tends to accumulate at defects, deteriorating low-temperature impact toughness. Like C, N is prone to segregate at dislocations, forming Cottrell atmospheres, leading to strain concentration. Therefore, in the invention, N is controlled as an impurity element, the content of N is limited to 0.0050% or less.

[0027] Ti and Nb are added to form nitrides with N, which reduces the adverse effects of N. To further eliminate the adverse effects of N, it is preferable that the contents of N, Nb, and Ti satisfy the relationship: $5.68N \leq Nb+Ti \leq 0.044$, preferably $6.65N \leq Nb+Ti \leq 0.04$.

[0028] Cu/Ni: since the melting point of Cu is only about 1083°C, lower than that of the steel matrix, excessive Cu leads to cracks during heating and hot rolling, leading to copper embrittlement and deteriorating surface properties. The addition of appropriate amount of Ni can suppress the copper embrittlement caused by Cu and improve low temperature impact toughness. However, since Ni is an expensive alloying element, excessive Ni increases manufacturing costs. Research shows that maintaining a Cu/Ni ratio of 2.0 or less is sufficient to address the copper embrittlement issue caused by the addition of Cu. Therefore, the ratio is limited to $Cu/Ni \leq 2.0$.

[0029] Nb is a strong carbide and nitride forming element, capable of combining with carbon and nitrogen in steel to form intermediate phases such as NbC, Nb(CN), and NbN. The fine carbide particles formed can refine the microstructure and enhance a precipitation strengthening effect, significantly increasing the strength of the steel plate. Moreover, Nb can inhibit the expansion of austenite interface, increasing the recrystallization temperature of the steel, thus allowing rolling in the non-recrystallization zone at higher temperatures. Therefore, adding an appropriate amount of Nb to the steel is beneficial for improving strength. The carbonitrides formed by Nb can pin the austenite grain boundaries during austenitization, inhibiting abnormal grain growth of austenite, which is beneficial for improving the toughness of the steel plate after quenching. However, a high content of Nb is detrimental to welding, as it easily forms brittle metal hydrides with hydrogen. These hydrides have significantly different plasticity and toughness compared to the matrix and have poor bonding with the matrix, leading to delayed cracking. The recommended content of Nb is 0.01-0.03%.

[0030] Ti plays a role in inhibiting the growth of austenite grains during the reheating of slabs and suppressing the growth of ferrite grains during the recrystallization controlled rolling process, thereby improving the toughness of the steel. In addition, Ti preferentially combines with N in the steel, reducing the amount of AlN. However, an excessive content of Ti is detrimental to low temperature impact toughness, and like Nb, it easily forms brittle hydrides with hydrogen, which is unfavorable for resistance to delayed cracking. Therefore, the addition of Ti is 0.01-0.03%.

[0031] Preferably, to further improve performance, the steel plate of the present invention can optionally add one or more of Cr, W, Mo, Sb, REM, V, and Ca, in the following amounts: Cr≤2.0%, W: 0.01-0.5%, Mo: 0.01-0.5%, Sb: 0.01-0.2%, REM: 0.01-0.2%, V: 0.01-0.2%, and Ca: 0.001-0.01%.

[0032] Cr is an important corrosion resistant element and has a solid solution strengthening effect. The addition of Cr can effectively increase the self-corrosion potential of steel and inhibit the occurrence of corrosion, thereby significantly reducing the promotion of material failure corrosion during wear and improving the erosion-corrosion resistance. Especially, with the improvement of corrosion resistance performance, the amount of hydrogen released during the corrosion process decreases, thereby enhancing resistance to delayed cracking. However, Cr is an expensive alloying element, and a high Cr content promotes the formation of protective rust layers on the steel surface, which quickly detach under abrasive environments, accelerating material failure due to wear. Therefore, the addition is selected, and its content is limited to a maximum of 2.0%.

[0033] W in steel forms carbides, which provides secondary hardening and solid solution strengthening effects. During over-aging, W also inhibits the segregation of impurity atoms and non-metallic inclusions at grain boundaries, thereby improving fracture toughness. Mo has phase transformation strengthening and dislocation strengthening effects, which enhance tempering stability of steel, reduce tempering softening, inhibit high-temperature temper brittleness, and improve low-temperature impact toughness of the steel plate. Sb combines with Cu in steel to form a Cu_2Sb film on the surface, thereby improving corrosion resistance. The addition of REM is beneficial for enhancing corrosion resistance. In steel, REM forms compounds, intermetallic compounds with iron (REM/Fe), and solid solution of rare earths, which hydrolyze in thin corrosion liquid film and precipitate at the cathode under higher pH conditions, thereby providing a corrosion-inhibiting effect. V is also a strong carbide and nitride forming element. It precipitates during phase transformations, providing both solid solution strengthening and precipitation strengthening through the formation of carbides and nitrides. V also increases tempering stability, thereby improving strength. Ca added to steel modifies the shape of sulfides, suppressing S-induced hot shortness and improving toughness.

[0034] The steel grade developed based on the above composition not only possesses high strength and hardness but also has a high self-corrosion potential, which inhibits corrosion and improves erosion-corrosion resistance (the erosion-corrosion resistance is two times or more that of ordinary Q235B steel plate). After heat treatment, the steel achieves a high-strength martensitic structure with a yield strength of ≥ 1100MPa, tensile strength of ≥ 1300MPa, elongation of ≥ 12%, hardness of 450±30HBW, and an impact energy at -40°C ≥ 60J. The steel grade exhibits excellent wear resistance, and with the improvement in corrosion resistance, it demonstrates good erosion-corrosion resistance. Through composition design and performance optimization, the steel grade achieves good resistance to delayed cracking (crack initiation time of 600 hours or more). The high strength dredging pipe made from this steel is particularly suitable for the transportation of large particles, high-density slurries, and are resistant to cracking and leakage during use.

[0035] Furthermore, the present application provides a method for manufacturing the aforementioned steel plate, which comprises the following steps:

1) Smelting and Casting

A molten steel is smelted and cast to obtain a casting slab;

2)Heating the Casting Slab
A heating temperature is 1230°C or higher, and a total heating time in a heating furnace is not less than 2 hours, wherein a holding time in a soaking zone is not less than 40 minutes;

3)Rough Rolling and Finish Rolling

In the rough rolling stage, a reduction rate per pass is 15% or more, and/or a reduction amount per pass is 25mm or more, and/or a total pass deformation ratio is greater than 80%;

In the finish rolling stage, a reduction rate of a last pass is not less than 16%, with a finish rolling temperature of ≥ 880°C, preferably 880-898°C;

4) Cooling and Coiling
Laminar cooling is used, cooling to 550-680°C, then coiling;

5) Quenching and Tempering

A quenching temperature is 820-845°C, a quenching holding time T1 in minute is 1.5H-2H, where H represents a plate thickness in mm; after leaving a furnace, the steel plate is water quenched to room temperature at a cooling rate of ≥ 50°C/s;

A tempering temperature is 200-240°C with a tempering holding time T2 in minute of 2H-3H, where H represents the plate thickness in mm, and T2 ≥ 12 minutes;

6)Finishing treatment

[0036] Straightening and edge cutting.

[0037] Preferably, in step 1), the casting slab is loaded hot into a furnace after casting is completed. That is, after confirming there are no surface quality issues, the casting slab is directly transported from the casting area to the heating furnace for heating and holding via rollers, thereby reducing energy consumption. If hot loading is not possible, the casting slab must be placed in an insulation pit for slow cooling, and only after the temperature drops to 200°C or lower can it be removed for air cooling.

[0038] Preferably, in step 4), the steel is cooled to 560-680°C and then coiled.

[0039] Preferably, in step 5), the quenching temperature is 828-845°C.

[0040] Preferably, in step 5), the tempering temperature is 210-240°C, more preferably 220-240°C.

[0041] Preferably, in step 5), the steel coil cooled to room temperature is uncoiled, straightened, and then cut into plates, followed by quenching and tempering treatments.

[0042] Preferably, the thickness of the obtained erosion-corrosion resistance steel plate is 8-20 mm.

[0043] In the manufacturing method of the steel plate of the present invention:
Before rolling, the casting slab is heated and held at a temperature of 1230°C or above. The heating and holding of the casting slab in the heating furnace is divided into preheating, heating, and soaking stages. The present invention requires that the total heating time of the casting slab in the furnace be no less than 2 hours, with the soaking stages lasting no less than 40 minutes. In addition, the casting slab can be hot-loaded into the furnace immediately after casting is completed. That is, after confirming that there are no surface quality issues, the casting slab is directly transported from the casting area via rollers to the heating furnace for heating and holding, thereby reducing energy consumption. If hot loading is not possible, the casting slab must be placed in an insulation pit for slow cooling, and can only be removed for air-cooling after the temperature drops to 200°C or lower.

[0044] Rolling is divided into two stages: rough rolling and finish rolling. To obtain fine original austenite grain size, the casting slab is rolled with a large reduction rate during the rough rolling stages. Under the condition that the rolling mill load allows, the reduction per pass is controlled to be 15% or above and/or the reduction per pass is 25mm or more. To achieve a fine grain size and a good plate shape, the total deformation ratio in the rough rolling stage can be controlled to be greater than 80%, and/or the reduction rate of the last pass in finish rolling is not less than 16%. In the invention, the "deformation ratio" refers to the ratio (percentage) of the reduction in thickness after rolling to the initial thickness: i.e., deformation ratio = (initial thickness - current thickness) / initial thickness * 100%.

[0045] Since the present invention involves offline heat treatment after rolling, there are no special requirements for the rolling temperature of the casting slab. However, to reduce the rolling load, the highest possible finish rolling and coiling temperature are used. According to the continuous transformation curve shown in Figure 1, the α→γ transformation point of the steel grade is approximately 780°C. Therefore, it is recommended to use a finish rolling temperature of 880°C or above. This ensures complete austenitization during rolling, which in turn results in lower and more stable rolling loads. This is beneficial for obtaining high-quality plate shape in subsequent processes. For thicker the steel plates, the finish rolling temperature can be appropriately reduced, but it should not be lower than 850°C. After rolling, the steel coil is cooled by laminar cooling to a temperature between 550-680°C before coiling. If the temperature is too high, the cooling rate will be too slow, leading to coarse grains in the steel coil, which is detrimental to the coiler. If the temperature is too low, bainitic structure is likely to form, increasing the strength of the steel plate and making subsequent uncoiling and straightening more difficult.

[0046] After cooling to room temperature, the steel coil is uncoiled, straightened, and cut into plates. The steel plates then undergo quenching and tempering treatments to achieve high strength and hardness, ensuring good wear resistance.

[0047] The quenching temperature directly affects the grain size of the subsequent martensitic structure, thereby influencing the toughness of the steel plate. To ensure full austenitization of the matrix, a heating temperature 30-50°C above the Ac3 point is generally used. If the heating temperature is too high, the austenite grains may coarsen, resulting in a coarse martensitic structure after quenching and a deterioration in toughness. If the heating temperature is too low, it leads to insufficient austenitization, resulting in incomplete martensitic formation after quenching and negatively affecting toughness. The holding time also follows a similar pattern for quenching. If the holding time is too long, it can lead to grain coarsening, increased energy consumption, and higher costs. Conversely, if the holding time is too short, it results in insufficient austenitization, and the hardness and strength of the steel after quenching do not meet the required standards. To achieve excellent low-temperature toughness, the present invention specifically employs a critical zone quenching process for the heat treatment of the steel plates. In quenching structure of the critical zone, there exists undissolved acicular ferrites. Although these undissolved acicular ferrites may slightly reduce the strength of the steel plate, they reach the strength limit before martensite under external force, causing cracks to initiate and propagate within them first, absorbing energy and thereby improving toughness. Therefore, the quenching temperature is controlled between -5°C and 20°C above the Ac3 point, i.e., between 820-845°C, thereby obtaining better low temperature toughness. The quenching holding time T1 is calculated from the moment the center of the plate reaches the temperature, and the time (in minute) is 1.5-2 times the plate thickness H (in mm). After the steel plate leaves the furnace, it is directly water-quenched to room temperature with a cooling rate of ≥ 50°C/s.

[0048] The tempering treatment mainly relieves and eliminates quenching stresses and improves plasticity and toughness. However, a high tempering temperature can cause the strength and hardness of the steel plate to decrease excessively, failing to comply with the design requirements and resulting in increased production costs. Therefore, it is imperative to control the tempering process parameters for the steel plate. In the present invention, the steel plate is tempered in the temperature range of 200-240°C. The tempering holding time T2 is calculated from the moment of the center of the plate reaches the temperature, and the time T2 (in minute) is 2-3 times the plate thickness H (in mm), but not less than 12 minutes. Finally, the quenched and tempered steel plate undergoes finishing treatment (straightening and trimming). After passing performance tests, the steel plate is released for shipment.

[0049] In an exemplary embodiment, the process route is as follows: deep desulfurization of molten iron (to ensure low S content in the steel) →combined top and bottom blowing in the converter (to control C content) →secondary refining → continuous casting (machine cleaning) →reheating of slab -controlled rolling -controlled cooling →coiling →uncoiling → straightening →plate cutting →heat treatment (quenching and tempering) →finishing →delivery.

[0050] The process of the present invention can achieve the production of high-hardness erosion-corrosion resistant steel plates with a thickness of 8-20mm. The yield strength of the steel plate is 1100 MPa or more, the tensile strength is 1300 MPa or more, the elongation is ≥ 12%, the hardness is 450±30 HBW, and the impact energy at -40°C is ≥ 60 J. Combined with the corrosion resistant design of the steel grade, the steel plate exhibits erosion-corrosion resistance and delayed cracking resistance. In the environments where large particles and high-density seawater slurries are transported, the erosion-corrosion resistance can be two times or more that of ordinary Q235B steel pipes.

[0051] The advantages of the present invention are as follows:

The present invention adopts a simple and economical C-Mn composition design, supplemented with small amounts of Nb and Ti microalloying elements, obtaining high hardness of the steel grade. The addition of corrosion resistant elements such as Cu, Ni, and Cr increases the matrix potential, inhibiting corrosion and improving the corrosion resistance of the steel plate. Therefore, the steel exhibits excellent erosion-corrosion resistance in corrosive wear environments, particularly in the environments where large particles and high-density seawater slurries are transported, the erosion-corrosion resistance is twice or more that of ordinary steel pipes.

[0052] The present invention relates to a steel grade with excellent low temperature impact toughness and cold bending properties, meeting the requirements for subsequent pipe manufacturing. The steel can be easily formed into high-hardness steel plates using existing equipment.

[0053] The present invention relates to a steel grade with good low temperature impact toughness and corrosion resistance, significantly improving the resistance to delayed cracking, and reducing the risk of cracking and leakage during the service of dredging pipes, thereby enhancing dredging efficiency and lowering maintenance costs.

[0054] The production process of the steel grade involved in the present invention is simple, and the content of expensive alloy elements is low, reducing difficulty and cost of the production, which is beneficial for the widespread adoption of the steel grade.

[0055] Specifically designed for the operating conditions of the dredging pipelines, the present invention provides an erosion-corrosion resistant steel plate with high hardness. After heat treatment, the steel plate forms a high-hardness martensitic structure with the following properties: yield strength ≥ 1100MPa, tensile strength ≥ 1300MPa, elongation ≥ 12%, hardness of 450±30 HBW, and impact energy at -40°C ≥ 60J. The steel plate exhibits excellent wear resistance, and with the improvement in corrosion resistance, the erosion-corrosion resistance reaches 2 times or more that of conventional carbon steel materials. In addition, the steel plate has good resistance to delayed cracking, making it easy to weld and cold bend. The high-strength dredging pipes made from this steel plate are particularly suitable for the transportation of large particles and high-density slurries, and they are not prone to cracking and leakage during use. These properties are not found in other known patented steel grades.

[0056] Compared to the prior art, the steel grade involved in the present invention has significant differences in composition and properties compared to comparative patents:
In terms of composition, the comparative patent 1 (CN102776445A) requires the addition of 0.01-1.0% Mo, Ca, and REM, and specifies a nitrogen (N) content of 0.01-0.1% to enhance strength. The upper limit for manganese (Mn) content is 5%, approaching the composition of medium-manganese steel.

[0057] The comparative patent 2 (CN101886225A) specifies high contents of C, Mn, and Cr, ranging from 0.4-0.9%, 14-16%, and 5-10%, respectively. In addition, it requires the addition of multiple rare elements such as Pr, Dy, Gd, and Nd.

[0058] The comparative patent 3 (CN10893001A) has a lower Cr content but a higher Al content, which is detrimental to toughness. In contrast, the steel grade of the present invention improves corrosion resistance through the addition of Si, Cr, Cu, and Ni, with the contents of these elements differing from those in the comparative patent 3.

[0059] Furthermore, the performance requirements of the steel in the present invention also differ from those disclosed in comparative patents 1-3.

[0060] The steel in the invention requires a yield strength of 1100MPa or more, an elongation of ≥ 12%, and a low temperature impact energy at -40°C of ≥ 60J, with clear resistance to delayed cracking, which are properties not found in the steel grades of comparative patents 1-3. Wherein, the yield strength range of the comparative patent 1 is relatively broad, from 300 MPa to 2500 MPa. While it can achieve very high strength, this comes at the expense of reduced plasticity, and the elongation cannot be guaranteed, limiting the application range. Comparative patent 2 achieves a hardness exceeding 50 HRC through high contents of strengthening elements, but the cost is too high and the elongation cannot be guaranteed, affecting its workability. Moreover, comparative patents 1 and 2 lack good low-temperature impact toughness.

BRIEF DESCRIPTION OF THE DRAWING

[0061] Figure 1 is the CCT curve of the steel described in the present invention.

DETAILED DESCRIPTION

[0062] The present invention is further described in conjunction with the following embodiments, but the invention is not limited to these embodiments.

Examples 1-22

1) Smelting and Casting

[0063] The molten steel was smelted in a 500kg vacuum induction furnace and cast into a 100 kg casting slab.

2) Casting slab heating

[0064] The heating temperature was 1230°C or above, and the total heating time in the heating furnace was not less than 2 hours, wherein the holding time in the soaking zone was not less than 40 minutes.

3) Rough rolling and finish rolling

[0065] In the rough rolling stage, the reduction rate per pass was controlled at 15% or above, and/or the reduction amount per pass was 25mm or more, and/or the total pass deformation ratio was greater than 80%;

[0066] In the finish rolling stage, the reduction rate of the last pass was not less than 16%, and finish rolling temperature was ≥ 880°C.

4) Cooling and coiling

[0067] Cooling was carried out to 550-680°C, followed by coiling.

5) Quenching and tempering

[0068] The quenching heating temperature was 820-845°C, the quenching holding time T1 (in minute) was 1.5H-2H, where H represents the plate thickness in mm; after leaving the furnace, the steel plate was water quenched to room temperature at a cooling rate of ≥ 50°C/s;

[0069] The tempering temperature was 200-240°C, the tempering holding time T2 (in minute) was 2H-3H, where H represents the plate thickness in mm, and T2 ≥ 12 minutes.

6) Finishing treatment

[0070] This included straightening and edge cutting.

Comparative Examples 1-4

[0071] Comparative Examples 1-4 are manufactured using methods similar to those of the Examples. However, one or more of the element compositions and manufacturing processes in Comparative Examples 1-4 do not fall within the scope of the present invention.

[0072] Table 1 shows the composition of the steel plate in the Examples and Comparative Examples. Table 2 displays some of the process parameters for the Examples and Comparative Examples, Table 3 shows the performance parameters of the Examples and Comparative Examples.

[0073] The cracking time was measured as follows: The resistance to delayed cracking of the steel plate was evaluated using a U-bend immersion test. Sample of 2*20*90 mm was bent into U-shape with a radius of 10mm. The sample was loaded with fixtures until both sides of the sample parallel. The sample was subsequently immersed in a 0.1mol/L hydrochloric acid solution, with the solution being replaced every 24 hours. The samples are observed twice daily during the test, and the exact cracking time was confirmed through video playback, recording the cracking time of the sample. The shorter cracking time of the sample indicates poorer resistance to the delayed cracking, which implies a higher risk of delayed cracking under corrosive conditions. Generally, it is considered that no cracking for more than 300 hours indicates good resistance to delayed cracking.

[0074] As shown in Table 3, the present invention relates to the steel plates all reach a hardness level of 450 HBW, and their tensile properties also meet the design requirements, demonstrating excellent erosion-corrosion resistance (the erosion-corrosion resistance of the steel plates in the present invention in two times or more that of ordinary Q235B steel plates). Particularly, the delayed cracking time of the steel plates in the present application was 600 hours or more, demonstrating their excellent resistance to delayed cracking.

[0075] The present invention was compared with conventional 450HBW-level wear-resistant steel as comparative examples.

[0076] Comparative Examples 1-4 were designed using a C-Si-Mn composition design, with a Mn content of about 1.6%, and a Cr content ranging from 0.4% to 1.2%, without adding Cu and Ni. Comparative Example 1 employed a final rolling temperature of 820°C, but the impact energy at -40°C was only 33J, and cracking occurred in 48 hours during the U-bend immersion test, indicating significantly lower low-temperature toughness and delayed cracking resistance compared to the steel of the present invention. Comparative Examples 2-4 used final rolling temperature of 880-900°C, with the low-temperature impact energies at -40°C of 23-33J, and the maximum cracking time in the U-bend immersion test was only 57 hours, which is much lower than that of the steel in the present invention. Therefore, the steel plate of Comparative Examples did not possess the required resistance to delayed cracking for dredging conditions and are not suitable for the manufacture of dredging pipelines.

[0077] The present invention relates to the erosion-corrosion resistant steel plates that can be used for the manufacture of slurry dredging pipes. They are applicable in various fields such as land reclamation, channel dredging, inland river silt removal, and mineral slurry transportation. The steel plates can replace the currently used ordinary dredging pipelines made of Q235B and Q345B grade steels, thereby improving production efficiency and reducing operational costs.

Table 1 (in wt%)

Number	C	Si	Mn	P	S	Al	Cu	Ni	B	N	Nb	Ti	Nb+Ti	(Nb+Ti)/N	Cu/Ni	Cr	W	Mo	Sb	REM	V	Ca
Example 1	0.174	0.122	1.35	0.011	0.004	0.022	0.42	0.28	0.0012	0.0042	0.021	0.012	0.033	7.86	1.5		0.11					
Example 2	0.212	0.253	1.13	0.012	0.0045	0.018	0.48	0.29	0.0017	0.0031		0.029	0.029	9.35	1.7			0.44			0.02	
Example 3	0.203	0.281	1.34	0.014	0.006	0.032	0.49	0.26	0.0018	0.0038	0.028		0.028	7.37	1.9					0.18		
Example 4	0.211	0.193	1.21	0.009	0.003	0.024	0.58	0.29	0.0026	0.0035	0.011	0.028	0.039	11.14	2.0	1.5						0.005
Example 5	0.185	0.126	1.36	0.011	0.004	0.028	0.16	0.22	0.0014	0.0044	0.012	0.013	0.025	5.68	0.7			0.23	0.04			
Example 6	0.193	0.234	1.18	0.012	0.0045	0.019	0.41	0.24	0.0016	0.0031		0.029	0.029	9.35	1.7							
Example 7	0.187	0.172	1.37	0.011	0.004	0.035	0.25	0.23	0.0015	0.0045	0.022	0.012	0.034	7.56	1.1		0.05	0.14				
Example 8	0.192	0.263	1.08	0.012	0.0045	0.018	0.43	0.29	0.0024	0.0041		0.028	0.028	6.83	1.5						0.03	
Example 9	0.218	0.284	1.32	0.014	0.006	0.033	0.29	0.18	0.0028	0.0039	0.024		0.024	6.15	1.6	1.8				0.09		
Example 10	0.213	0.134	1.23	0.009	0.003	0.024	0.58	0.31	0.0027	0.0043		0.029	0.029	6.74	1.9			0.24				0.008
Example 11	0.195	0.147	1.38	0.007	0.004	0.028	0.34	0.19	0.0014	0.0044	0.012	0.013	0.025	5.68	1.8							
Example 12	0.204	0.168	1.22	0.006	0.0045	0.019	0.41	0.25	0.0016	0.0031		0.029	0.029	9.35	1.6	1.8						
Example 13	0.188	0.113	1.37	0.013	0.004	0.035	0.38	0.21	0.0015	0.0045	0.022	0.012	0.034	7.56	1.8				0.09			
Example 14	0.216	0.232	1.05	0.008	0.0045	0.018	0.43	0.27	0.0024	0.0041		0.028	0.028	6.83	1.6			0.41				
Example 15	0.215	0.241	1.33	0.014	0.006	0.033	0.49	0.26	0.0028	0.0039	0.024		0.024	6.15	1.9	0.5						
Example 16	0.214	0.192	1.24	0.013	0.003	0.024	0.37	0.25	0.0027	0.0043	0.015	0.029	0.044	10.23	1.5						0.05	
Example 17	0.194	0.181	1.280	0.011	0.0039	0.027	0.18	0.12	0.0018	0.0023	0.014	0.015	0.029	12.61	1.5		0.5			0.01		
Example 18	0.189	0.199	1.248	0.007	0.0043	0.025	0.31	0.17	0.0017	0.0040	0.021	0.017	0.038	9.50	1.8	1.9		0.01				
Example 19	0.198	0.238	1.238	0.012	0.0048	0.026	0.24	0.24	0.0021	0.0027	0.023		0.023	8.52	1.0				0.2			
Example 20	0.203	0.213	1.250	0.009	0.0022	0.028	0.21	0.13	0.0024	0.0032	0.022		0.022	6.88	1.6		0.01					0.0011
Example 21	0.205	0.207	1.253	0.011	0.0031	0.026	0.16	0.22	0.0023	0.0041	0.018	0.011	0.029	7.07	0.7				0.01			
Example 22	0.208	0.183	1.288	0.014	0.0044	0.026	0.27	0.14	0.0021	0.0033	0.024		0.024	7.27	1.9						0.2	
Comparative Example 1	0.21	***0.02***	***1.61***	0.015	0.004	0.032			0.0018	0.0042	0.013	0.017	0.03	7.14		0.4						
Comparative Example 2	0.22	0.21	***1.56***	0.009	***0.006***	***0.042***			0.0022	0.0037		***0.035***	0.035	9.46		0.8						
Comparative Example 3	0.19	0.14	***1.58***	***0.022***	***0.011***	0.024			0.0013	0.0032	0.023	0.011	0.034	10.63		1.2						
Comparative Example 4	***0.23***	0.23	***1.57***	***0.016***	***0.009***	0.03			0.0016	0.0036	0.018	***0.046***	***0.064***	17.78		0.6						

Table 2

Number	Thickness mm	Finishing rolling temperature °C	Coiling temperature °C	Quenching temperature °C	Quenching holding time T1 minute	Tempering temperature °C	Tempering holding time T2 minute
Example 1	8	892	680	820	15	210	20
Example 2	10	894	664	842	18	210	22
Example 3	8	895	678	833	15	210	20
Example 4	12	893	615	835	18	230	25
Example 5	12	895	612	841	20	230	26
Example 6	15	881	604	843	24	240	30
Example 7	18	884	596	828	30	240	40
Example 8	20	889	588	844	30	240	45
Example 9	14	882	572	840	22	220	30
Example 10	16	884	560	837	25	220	35
Example 11	12	883	575	823	20	200	25
Example 12	15	891	581	834	25	200	32
Example 13	14	887	564	826	22	210	32
Example 14	16	886	572	827	28	210	35
Example 15	18	896	564	830	30	220	42
Example 16	20	898	568	845	32	220	45
Example 17	13	887	604	837	18	200	28
Example 18	15	885	596	838	24	200	33
Example 19	12	885	585	837	20	200	25
Example 20	14	885	573	840	26	210	35
Example 21	16	883	569	833	30	220	34
Example 22	10	886	572	831	16	210	21
Comparative Example 1	8	-	-	820 15	15	240	***30***
Comparative Example 2	10	-	-	***880***	20	240	30
Comparative Example 3	14	-	-	***900***	25	240	35
Comparative Example 4	16	-	-	***880***	30	240	40

Table 3

Number	Yield strength MPa	Tensile strength MPa	Elongation A50 %	Hardness HBW	-40°C AKV J	Cracking Time hour
Example 1	1155	1367	15	441	49 (65)*	682
Example 2	1196	1384	14	450	66	649
Example 3	1229	1490	15	449	52 (69)*	711
Example 4	1255	1484	14	451	64	820

(continued)

Number	Yield strength MPa	Tensile strength MPa	Elongation A50 %	Hardness HBW	-40°C AKV J	Cracking Time hour
Example 5	1139	1494	13	458	78	740
Example 6	1129	1393	16	446	72	721
Example 7	1219	1492	17	454	84	842
Example 8	1270	1488	19	452	66	842
Example 9	1197	1489	15	455	71	780
Example 10	1134	1444	16	452	75	731
Example 11	1179	1440	17	449	79	680
Example 12	1201	1391	18	448	97	766
Example 13	1180	1347	18	447	76	780
Example 14	1195	1310	20	439	70	731
Example 15	1194	1480	20	446	83	782
Example 16	1190	1467	21	457	77	840
Example 17	1162	1460	15	453	79	768
Example 18	1206	1458	17	451	85	802
Example 19	1229	1490	17	454	79	821
Example 20	1200	1474	17	453	86	784
Example 21	1170	1458	16	452	88	730
Example 22	1171	1425	17	450	63	725
Comparative Example 1	1247	1533	13	458	***33 (44)****	***48***
Comparative Example 2	1227	1510	13	462	***23***	***57***
Comparative Example 3	1242	1515	12	456	***31***	***52***
Comparative Example 4	1224	1530	12	459	***33***	***44***
Note: *For Examples 1 and 3, and Comparative Example 1, the -40°C AKV values in parentheses are corrected values. The steel plate thickness of Examples 1 and 3, and Comparative Example 1 is 8 mm, with the impact test specimen dimensions of 7.5 x 10 x 55mm, while the full-size impact specimen dimension is 10 x 10 x 55mm. Therefore, when the specimen converts to the full-size impact specimen, the corrected values for Examples 1 and 3, and Comparative Example 1, are respectively as follow: 49*(10/7.5)=65J, 52*(10/7.5)=69J, and 33*(10/7.5)=44J.						

Claims

1. A steel plate, comprising the following chemical elements in wt%: C: 0.17-0.22%, Si: 0.1-0.3%, Mn: 1.0-1.4%, $P \leq 0.015\%$, $S \leq 0.005\%$, Al: 0.018-0.04%, Cu: 0.15-0.60%, Ni: 0.1-0.31%, B: 0.001-0.003%, $N \leq 0.005\%$, and one or both of Nb: 0.01-0.03% and Ti: 0.01-0.03%, with the balance being Fe and inevitable impurities;

   contents of elements N, Nb, and Ti satisfy the following inequality: $5.68N \leq Nb+Ti \leq 0.044$;
   contents of elements Cu and Ni satisfy the following inequality: $Cu/Ni \leq 2.0$.

2. The steel plate according to claim 1, wherein the steel plate further comprises one or more of the following: $Cr \leq 2.0\%$, W: 0.01-0.5%, Mo: 0.01-0.5%, Sb: 0.01-0.2%, REM: 0.01-0.2%, V: 0.01-0.2%, and Ca: 0.001-0.01%.

3. The steel plate according to claim 1 or 2, wherein the steel plate satisfies one or more of the following:

Cu: 0.29-0.60%;
$6.65N \leq Nb+Ti \leq 0.04$;
$0.7 \leq Cu/Ni \leq 2.0$.

4. The steel plate according to claim 1 or 2, wherein a thickness of the steel plate is 8-20 mm.

5. The steel plate according to claim 1 or 2, wherein the steel plate satisfies one or more of the following properties: yield strength≥1100 MPa; tensile strength≥1300 MPa; elongation≥12%; hardness of 450±30 HBW; -40°C impact energy≥60 J; cracking time≥600 hours.

6. The steel plate according to claim 5, wherein an erosion-corrosion resistance of the steel plate is two times or more that of ordinary Q235B steel plate.

7. A method for manufacturing the steel plate according to any one of claims 1 to 6, wherein the method comprises the following steps:

1) smelting and casting
smelting and casting a molten steel to obtain a casting slab;
2) heating the casting slab
a heating temperature is 1230°C or higher, and a total heating time in a heating furnace is not less than 2 hours, wherein a holding time in a soaking zone is not less than 40 minutes;
3) rough rolling and finish rolling

in the rough rolling stage, a reduction rate per pass is 15% or above, and/or a reduction amount per pass is 25 mm or more, and/or a total pass deformation ratio is greater than 80%;
in the finish rolling stage, a reduction rate of a last pass is not less than 16%, with a finish rolling temperature of ≥ 880°C, preferably 880-898°C;

4) cooling and coiling
cooling to 550-680°C, then coiling;
5) quenching and tempering
a quenching temperature is 820-845°C, a quenching holding time T1 in minute is 1.5H-2H, wherein H represents a plate thickness in mm; after leaving a furnace, the steel plate is water-quenched to room temperature at a cooling rate of ≥ 50°C/s; a tempering temperature is 200-240°C with a tempering holding time T2 in minute of 2H-3H, wherein H represents the plate thickness in mm, and $T2 \geq 12$ minutes;
6) finishing treatment
straightening and edge cutting.

8. The method according to claim 7, wherein in step 4), cooling to 560-680°C, followed by coiling.

9. The method according to claim 7 or 8, wherein in step 5), the quenching temperature is 828-845°C; and/or the tempering temperature is 210-240°C, preferably 220-240°C.

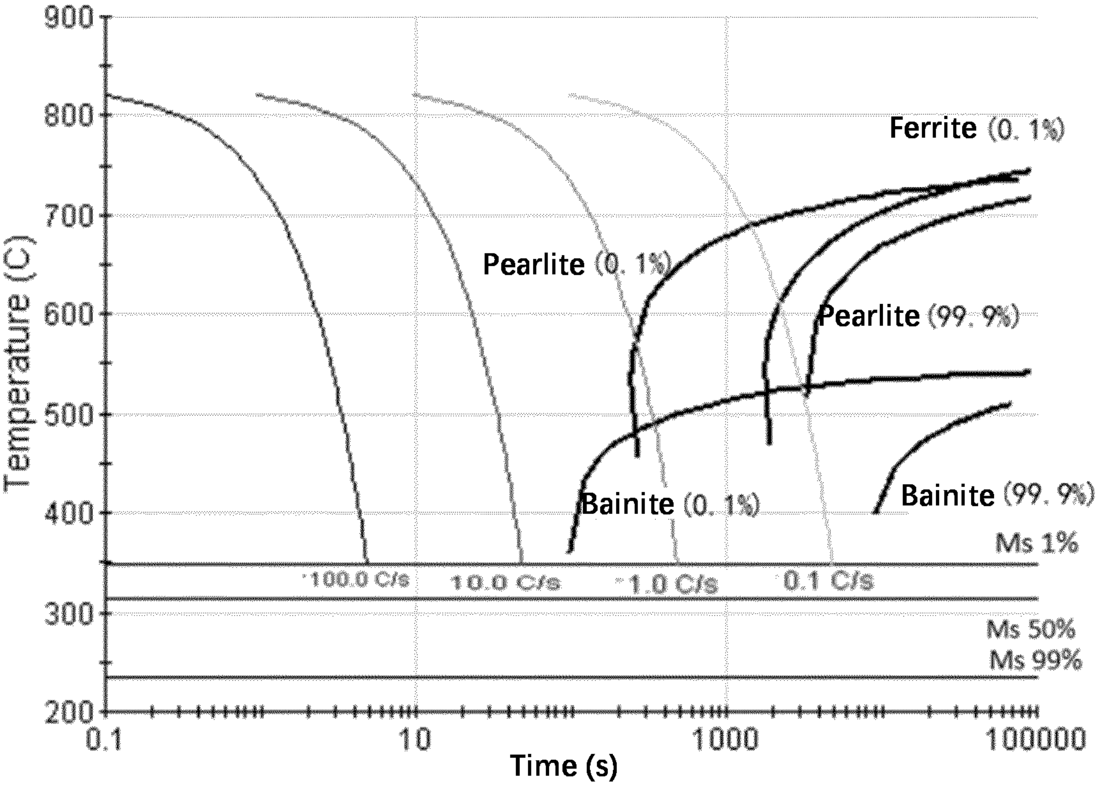
Temperature (C)
900
800
700
600
500
400
300
200
Time (s)
0.1
10
1000
100000
Ferrite (0. 1%)
Pearlite (0. 1%)
Pearlite (99. 9%)
Bainite (0. 1%)
Bainite (99. 9%)
Ms 1%
Ms 50%
Ms 99%
100.0 C/s
10.0 C/s
1.0 C/s
0.1 C/s

Figure 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2023/099335

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/60(2006.01)i; C22C38/12(2006.01)i; C22C38/00(2006.01)i; C21D9/46(2006.01)i; B21B1/26(2006.01)i; B21B1/28(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)

IPC: C22C C21D B21B

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)

CNTXT, DWPI, CNKI: 钢板, 断裂, 开裂, 强度, al, b, C, ca, cu, mn, mo, nb, ni, sb, si, ti, v, "w", steel, sheet, fracture resistance, strength

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2008208454 A (JFE STEEL K. K.) 11 September 2008 (2008-09-11) description, paragraphs 11-68, and tables 1-6	1-9
Y	JP 2015147957 A (JFE STEEL CORP.) 20 August 2015 (2015-08-20) description, paragraphs 8-56	1-9
A	JP 2004332099 A (NIPPON STEEL CORP.) 25 November 2004 (2004-11-25) entire document	1-9
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Date of the actual completion of the international search **12 July 2023**	Date of mailing of the international search report **25 July 2023**
Name and mailing address of the ISA/CN **China National Intellectual Property Administration (ISA/CN)** **China No. 6, Xitucheng Road, Jimenqiao, Haidian District, Beijing 100088**	Authorized officer Telephone No.

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