(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 279 626 A1

(12) EUROPEAN PATENT APPLICATION
published in accordance with Art. 153(4) EPC

(43) Date of publication:
22.11.2023 Bulletin 2023/47

(21) Application number: **21918802.6**

(22) Date of filing: **12.04.2021**

(51) International Patent Classification (IPC):
C22C 38/44 *(2006.01)* ***C22C 38/04*** *(2006.01)*
C22C 38/42 *(2006.01)* ***C22C 38/48*** *(2006.01)*
C22C 38/02 *(2006.01)* ***C22C 38/46*** *(2006.01)*
C22C 38/50 *(2006.01)* ***C22C 38/54*** *(2006.01)*
C22C 38/06 *(2006.01)* ***C21D 8/08*** *(2006.01)*

(86) International application number:
PCT/CN2021/086677

(87) International publication number:
WO 2022/151603 (21.07.2022 Gazette 2022/29)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **15.01.2021 CN 202110051522**

(71) Applicants:
- **Institute Of Research Of Iron And Steel, Jiangsu Province/Sha-Steel, Co. Ltd (CN) Suzhou, Jiangsu 215625 (CN)**
- **Jiangsu Shagang Group Co., Ltd. Jiangsu 215625 (CN)**

(72) Inventors:
- **MA, Han Suzhou, Jiangsu 215625 (CN)**
- **ZHOU, Yun Suzhou, Jiangsu 215625 (CN)**
- **ZHAO, Jiaqi Suzhou, Jiangsu 215625 (CN)**
- **ZHANG, Yu Suzhou, Jiangsu 215625 (CN)**
- **CHEN, Huande Suzhou, Jiangsu 215625 (CN)**

(74) Representative: **Gille Hrabal Partnerschaftsgesellschaft mbB Patentanwälte Brucknerstraße 20 40593 Düsseldorf (DE)**

(54) 400 MPA-GRADE CORROSION-RESISTANT STEEL BAR AND PRODUCTION METHOD THEREFOR

(57) The present invention discloses a 400 MPa corrosion-resistant steel bar and a production method thereof. The steel bar includes the following chemical ingredients: 9.5-10.4% of Cr, 1.0-1.2% of Mo, 0.3-0.6% of Mn, 0.01-1% of Ni, 0.01-0.5% of Cu, at most 0.014% of C, at most 0.004% of N, 0.01-0.05% of Nb, 0.2-0.6% of Si, and the balance of Fe, where Cr+Mo+0.5Mn+0.35Ni+0.25Cu is 11.1-12.2%, and C+N+0.3Si+Mn+1.8Nb is 0.4-0.8%.

Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to Chinese Patent Application No. 202110051522.4, entitled "400 MPa Corrosion-Resistant Steel Bar and Production Method Thereof, filed on January 15, 2021, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present invention belongs to the technical field of metallurgy, and relates to a 400 MPa corrosion-resistant steel bar and a production method of the 400 MPa corrosion-resistant steel bar.

BACKGROUND

[0003] Reinforced concrete structures are the most widely used structure form in infrastructure construction. The theoretical service life of the reinforced concrete structures is long, but there are many cases of premature failure of reinforced concrete in practical engineering, which not only increases the maintenance cost, but also causes great waste of energy and resources. According to the investigation, the coastal reinforced concrete structures are affected by high chloride ion and sulfate contents and harsh environments such as high temperature and high humidity, so after they are put in use for 10-15 years, serious corrosion damage may generally occur, and they are far from achieving the designed theoretical service life.

[0004] Concrete in the reinforced concrete structures belongs to a strong alkaline environment. In this alkaline environment, the surfaces of steel bars will be passivated to form a layer of stable metal oxide passivation film. In the practical use of the reinforced concrete structures, the dissolution and repair of the passivation film are theoretically in a nearly balanced state, so that the potential of various positions on the surface of the steel bars is basically consistent, thus ensuring that the steel bars are difficult to corrode or the corrosion rate is very low. However, when the passivation film on the surfaces of the steel bars is damaged by external corrosive substances, for example, in the marine environment, when active chloride ions on the passivation film on the surfaces of the steel bars reach a certain concentration, the dissolution and repair of the passivation film lose balance, the dissolution of the passivation film is accelerated, and corrosion pits are formed, so that steel bar matrixes may be exposed to corrosive media, and the failure of the reinforced concrete structures may be finally caused.

[0005] Although a certain effect may be achieved on prolonging the service life of the reinforced concrete structures by measures of corrosion inhibitors, surface protection layers, cathodic protection, coated steel bars, etc., as the core of reinforced concrete structures, improving the corrosion-resistant performance of matrixes of the steel bars is the key to the solution of the corrosion damage problem of the reinforced concrete structures.

[0006] In addition, besides the corrosion-resistant performance, the mechanical performance, welding performance, production and manufacturing costs of the steel bars are also important aspects affecting the practical production and application of the steel bars. For example, stainless-steel bars are a common type of steel bars with good corrosion-resistant performance. By adding a great number of alloy elements such as Cr, Ni and Mo, the corrosion-resistant performance of the stainless-steel bars may be greatly improved through being compared with that of common carbon-steel bars, and the corrosion-resistant performance is excellent. However, due to the addition of a great number of alloy elements into the stainless-steel bars, the welding performance of the stainless-steel bars is very poor, the welding construction cost of the stainless-steel bars in practical construction is very high, and there is also a risk of instability of the reinforced concrete structures due to poor welding. At the same time, due to the addition of a great number of alloy elements into the stainless-steel bars, the raw material cost and production cost of the stainless-steel bars are exponentially increased through being compared with those of ordinary steel bars. Therefore, the stainless-steel bars cannot be widely applied due to their high price, and do not conform to the social requirements of energy saving and consumption reduction. In addition, there is still a controversy about whether the macro cell corrosion will occur or not under the condition of overlapping of the stainless-steel bars and ordinary steel bars.

[0007] Therefore, how to ensure the corrosion-resistant performance, mechanical performance, welding performance and cost at the same time will be an important subject in the research of corrosion-resistant steel bars with significant social significance and economic effects.

SUMMARY

[0008] In order to solve the technical problems in the prior art, the present invention is directed to provide a 400 MPa corrosion-resistant steel bar which has excellent corrosion-resistant performance, comprehensive mechanical performance and welding performance, can be prepared at lower material cost and process cost and is suitable to be widely used in ocean engineering.

[0009] In order to achieve the above invention purposes, according to an embodiment, the present invention provides a 400 MPa corrosion-resistant steel bar. The steel bar includes the following chemical ingredients in percentage by mass: 9.5-10.4% of Cr, 1.0-1.2% of Mo, 0.3-0.6% of Mn, 0.01-1.00% of Ni, 0.01-0.5% of Cu, at most 0.014% of C, at most 0.004% of N, 0.01-0.05% of Nb, 0.2-0.6% of Si, at most 0.004% of S, at most 0.003% of O, at most 0.01% of As, 0.01-0.03% of P, and the balance of Fe and unavoidable impurities. Cr+Mo+0.5Mn+0.35Ni+0.25Cu is 11.1-12.2%, and C+N+0.3Si+Mn+1.8Nb is 0.4-0.8%.

[0010] Preferably, the steel bar further includes the following chemical ingredients in percentage by mass: any one or more of 0.1-0.15% of V, 0.01-0.05% of Ti, 0.01-0.03% of Al and 0.0005-0.0020% of B.

[0011] Further, a micro-structure of the steel bar is ferrite and bainite, and the ferrite accounts for 28%-40%.

[0012] Further, an A-type inclusion, B-type inclusion, C-type inclusion and D-type inclusion of the steel bar at the standard of GB/T10561 are all less than or equal to 1.0 level.

[0013] Further, a yield strength of the steel bar is greater than or equal to 420 MPa, a tensile strength is greater than or equal to 540 MPa, a percentage elongation after fracture is greater than or equal to 18%, and a maximum force total elongation percentage is greater than or equal to 7.5%.

[0014] Further, a nominal diameter of the steel bar is 6-32 mm.

[0015] Further, when the nominal diameter of the steel bar is 6-10 mm, the steel bar is made into a coiled steel bar; and when the nominal diameter of the steel bar is 12-32 mm, the steel bar is made into a straight steel bar.

[0016] Further, in a periodic infiltration corrosion test, an average weight loss corrosion rate of the steel bar is 0.05-0.1 g/(m^2·h); in a salt mist corrosion test, an average weight loss corrosion rate of the steel bar is 0.01-0.04 g/(m^2·h); and in simulated concrete pore fluid with the chloride ion concentration greater than or equal to 3 mol/L, a self-corrosion potential of the steel bar is -0.1 V to -0.15 V, a polarization resistance is 2500-3000 kΩ/cm^2, and a self-corrosion current density is less than or equal to 0.13 μA/cm^2.

[0017] Preferably, the steel bar is able to be prepared by a process route I and a process route II.

[0018] The process route I includes a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an AOD furnace refining working procedure, an LF furnace refining working procedure, a square billet continuous casting working procedure, a hot continuous rolling working procedure and a temperature-controlled cooling working procedure which are performed in sequence.

[0019] The process route II includes a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an LF furnace refining working procedure, an RH furnace refining working procedure, a square billet continuous casting working procedure, a hot continuous rolling working procedure and a temperature-controlled cooling working procedure which are performed in sequence.

[0020] Preferably, in the process route I: a tapping temperature of the converter smelting working procedure is 1600-1660°C; in the AOD furnace refining working procedure, high-carbon ferro-chrome alloy and ferro-molybdenum alloy are added into molten steel to realize preliminary alloying on the molten steel, slagging-off is performed after reduction, then, manganese alloy is added, before tapping, a steel ladle for tapping is purged by argon gas for 5 min or a longer time, 20 kg of aluminum ingots are added into the molten steel in the tapping process, a tapping temperature is 1630-1670°C, and a tapping C content is less than or equal to 0.01%; in the LF furnace refining working procedure, after the molten steel reaches the steel ladle of an LF furnace, slag regulation is performed according to a scheme of adding 13-15 kg of lime and 4.0-6.5 kg of fluorite into per ton of molten steel, a white slag maintaining time is greater than or equal to 8 min, a soft stirring time is 8-15 min, and a tapping temperature is 1600-1620°C; and in the square billet continuous casting working procedure, carbon-free protection slag or ultra-low-carbon protection slag is used, a continuous casting temperature is 1520-1560°C, and a drawing speed in the continuous casting process is 1.2-1.6 m/min.

[0021] Preferably, in the process route II: in the converter smelting working procedure, micro-carbon ferro-chrome alloy is added into molten steel in the tapping process to realize preliminary alloying on the molten steel, and a tapping temperature is 1700-1750°C; in the LF furnace refining working procedure, a steel ladle in an LF furnace is subjected to whole-process bottom blowing at an argon gas flow rate of 80-160 L/min, and a tapping temperature is 1560-1600°C; in the RH furnace refining working procedure, after vacuum pumping on an RH furnace for 3 min, oxygen is started to be blown into the RH furnace, a total oxygen blowing amount is 500-700 Nm^3, then, micro-carbon ferro-chrome alloy is added into molten steel to realize alloying on the molten steel, clean circulation treatment is performed for 5 min or a longer time when a vacuum degree is less than 2 mbar, a tapping temperature is 1560-1600°C, and a tapping C content is less than or equal to 0.015%; and in the square billet continuous casting working procedure, carbon-free protection slag or ultra-low-carbon protection slag is used, a continuous casting temperature is 1520-1560°C, and a drawing speed in the continuous casting process is 2.2-2.6 m/min.

[0022] Preferably, according to the process route I and the process route II:

in the hot continuous rolling working procedure, continuous-casting billets are heated in heating furnaces, a heating

temperature is 1100-1200°C, an in-furnace time is 60-120 min, then, the billets are rolled into straight thread steel bars with a diameter of 12-32 mm, an initial rolling temperature is 1000-1100°C, and a finish rolling temperature is 850-950°C; and
in the temperature-controlled cooling working procedure, the rolled straight thread steel bars are naturally cooled on a cooling bed, and a temperature on the cooling bed is 860-920°C.

[0023] Preferably, according to the process route I and the process route II: in the hot continuous rolling working procedure, continuous-casting billets are heated in heating furnaces, a heating temperature is 1080-1130°C, an in-furnace time is 60-120 min, then, the billets are rolled into coiled thread steel bars with a diameter of 6-10 mm, an initial rolling temperature is 980-1030°C, a finish rolling temperature is 850-950°C, and a spinning temperature is 830-920°C.
[0024] Preferably, both the process route I and the process route II include an on-line acid pickling working procedure and a packing working procedure which are performed in sequence after the temperature-controlled cooling working procedure; and in the on-line acid pickling working procedure, the steel bars sequentially pass through an acid pickling tank, a passivation tank and a drying device, and gas jet holes of the acid pickling tank are distributed around a center line of the acid pickling tank.
[0025] Further, when the two steel bars are connected into a welded sample through electric slag pressure welding, a breaking point of the obtained welded sample in a tensile test is formed in a base material position of the two steel bars.
[0026] Compared with the prior art, the present invention has the following beneficial effects:

(1) On the premise of an ultra-low carbon design, the respective contents and association relationships of Cr, Mo, Mn, Ni and Cu are properly designed, at the same time, the respective contents and association relationships of C, N, Si, Mn and Nb are properly designed, so that the steel bar has a two-phase micro-structure of ferrite and bainite in a reasonable proportion, and the overall comprehensive performance of the steel bar is excellent. Specifically, in an aspect of mechanical performance of the steel bar, a yield strength of the steel bar is greater than or equal to 420 MPa, a tensile strength is greater than or equal to 540 MPa, a percentage elongation after fracture is greater than or equal to 18%, and a maximum force total elongation percentage is greater than or equal to 7.5%. In an aspect of corrosion-resistant performance, in a periodic infiltration corrosion test and a salt mist corrosion test, the corrosion-resistant performance is improved by 45 times or greater through being compared with that of ordinary HRB400. In an electrochemical corrosion test, the positive shift amplitude of the self-corrosion potential relative to the ordinary HRB400 exceeds 0.4 V, a polarization resistance is much greater than that of ordinary HRB400, and a self-corrosion current density equals to 1/65 or even less of that of ordinary HRB400. In an aspect of welding performance, the welding is easy, a welding point structure is firm, breaking cannot easily occur, and a breaking point of a welded sample in a tensile test is formed in a base material position of the two steel bars.
(2) Under the condition of a design scheme of the chemical ingredients, the excellent corrosion-resistant performance, comprehensive mechanical performance and welding performance can be realized, in addition, the cost of alloy elements is low, the energy is saved, the consumption is reduced, the 400 MPa corrosion-resistant steel bar can be prepared through a plurality of process routes, the cost of the production process is reduced, and the present invention is suitable for practical production and processing, and has higher social significance and economic effects.

[0027] In order to solve the technical problems in the prior art, the present invention is directed to provide a production method of a 400 MPa corrosion-resistant steel bar. The steel bar prepared by the production method has excellent corrosion-resistant performance, comprehensive mechanical performance and welding performance, has lower material cost and process cost and is suitable to be widely used in ocean engineering.
[0028] In order to achieve the above invention purposes, according to an embodiment, the present invention provides a production method of a 400 MPa corrosion-resistant steel bar. The production method includes the following steps:

(1) steel making:
sequentially using a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an AOD furnace refining working procedure and an LF furnace refining working procedure for molten steel melting, or sequentially using a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an LF furnace refining working procedure and an RH furnace refining working procedure for molten steel melting, and making the molten steel into steel billets through continuous casting, where the steel billets include the following chemical ingredients in percentage by mass: 9.5-10.4% of Cr, 1.0-1.2% of Mo, 0.3-0.6% of Mn, 0.01-1.00% of Ni, 0.01-0.5% of Cu, at most 0.014% of C, at most 0.004% of N, 0.01-0.05% of Nb, 0.2-0.6% of Si, at most 0.004% of S, at most 0.003% of O, at most 0.01% of As, 0.01-0.03% of P, and the balance of Fe and unavoidable impurities, where Cr+Mo+0.5Mn+0.35Ni+0.25Cu is 11.1-12.2%, and C+N+0.3Si+Mn+1.8Nb is 0.4-0.8%; and
(2) controlled rolling and controlled cooling:

heating the steel billets obtained in Step (1) in a heating furnace at a heating temperature of 1100-1200°C for an in-furnace time of 60-120 min, then, rolling the steel billets into straight thread steel bars with a diameter of 12-32 mm at an initial rolling temperature of 1000-1100°C and a finish rolling temperature of 850-950°C; then, naturally cooling the rolled straight thread steel bars on a cooling bed at a temperature on the cooling bed of 860-920°C;

or heating the steel billets obtained in Step (1) in a heating furnace at a heating temperature of 1080-1130°C for an in-furnace time of 60-120 min, then, rolling the steel billets into coiled thread steel bars with a diameter of 6-10 mm at an initial rolling temperature of 980-1030°C, a finish rolling temperature of 850-950°C, and a spinning temperature of 830-920°C, then, cooling the rolled coiled thread steel bars in a delayed Stelmor cooling manner while all fans under a roller bed are turned off.

[0029] Preferably, in Step (1), the steel billets further include the following chemical ingredients in percentage by mass: any one or more of 0.1-0.15% of V, 0.01-0.05% of Ti, 0.01-0.03% of Al and 0.0005-0.0020% of B.

[0030] Preferably, in Step (1), if a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an AOD furnace refining working procedure and an LF furnace refining working procedure are sequentially used for molten steel melting, a tapping temperature of the converter smelting working procedure is 1600-1660°C; in the AOD furnace refining working procedure, high-carbon ferro-chrome alloy and ferro-molybdenum alloy are added into molten steel to realize preliminary alloying on the molten steel, slagging-off is performed after reduction, then, manganese alloy is added, before tapping, a steel ladle for tapping is purged by argon gas for 5 min or a longer time, 20 kg of aluminum ingots are added into the molten steel in the tapping process, a tapping temperature is 1630-1670°C, and a tapping C content is less than or equal to 0.01%; in the LF furnace refining working procedure, after the molten steel reaches the steel ladle of an LF furnace, slag regulation is performed according to a scheme of adding 13-15 kg of lime and 4.0-6.5 kg of fluorite into per ton of molten steel, a white slag maintaining time is greater than or equal to 8 min, a soft stirring time is 8-15 min, and a tapping temperature is 1600-1620°C; and in the square billet continuous casting working procedure, carbon-free protection slag or ultra-low-carbon protection slag is used, a continuous casting temperature is 1520-1560°C, and a drawing speed in the continuous casting process is 1.2-1.6 m/min.

[0031] If a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an LF furnace refining working procedure and an RH furnace refining working procedure are sequentially used for molten steel melting, in the converter smelting working procedure, micro-carbon ferro-chrome alloy is added into molten steel in the tapping process to realize preliminary alloying on the molten steel, and a tapping temperature is 1700-1750°C; in the LF furnace refining working procedure, a steel ladle in an LF furnace is subjected to whole-process bottom blowing at an argon gas flow rate of 80-160 L/min, and a tapping temperature is 1560-1600°C; in the RH furnace refining working procedure, after vacuum pumping on an RH furnace for 3 min, oxygen is started to be blown into the RH furnace, a total oxygen blowing amount is 500-700 Nm^3, then, micro-carbon ferro-chrome alloy is added into molten steel to realize alloying on the molten steel, clean circulation treatment is performed for 5 min or a longer time when a vacuum degree is less than 2 mbar, a tapping temperature is 1560-1600°C, and a tapping C content is less than or equal to 0.015%; and in the square billet continuous casting working procedure, carbon-free protection slag or ultra-low-carbon protection slag is used, a continuous casting temperature is 1520-1560°C, and a drawing speed in the continuous casting process is 2.2-2.6 m/min.

[0032] Preferably, the production method further includes Step (3) on-line acid pickling:

sequentially passing the steel bars obtained in Step (2) through an acid pickling tank, a passivation tank and a drying device for on-line acid pickling, where gas jet holes of the acid pickling tank are distributed around a center line of the acid pickling tank; and packing the steel bars after the steel bars leave away from the drying device.

[0033] Further, when the two steel bars prepared by the production method are connected into a welded sample through electric slag pressure welding, a breaking point of the obtained welded sample in a tensile test is formed in a base material position of the two steel bars.

[0034] Further, a micro-structure of the steel bar prepared by the production method is ferrite and bainite, and the ferrite accounts for 28%-40%.

[0035] Further, an A-type inclusion, B-type inclusion, C-type inclusion and D-type inclusion of the steel bar prepared by the production method at the standard of GB/T10561 are all less than or equal to 1.0 level.

[0036] Further, a yield strength of the steel bar prepared by the production method is greater than or equal to 420 MPa, a tensile strength is greater than or equal to 540 MPa, a percentage elongation after fracture is greater than or equal to 18%, and a maximum force total elongation percentage is greater than or equal to 7.5%.

[0037] Further, in a periodic infiltration corrosion test, an average weight loss corrosion rate of the steel bar prepared by the production method is 0.05-0.1 $g/(m^2 \cdot h)$; in a salt mist corrosion test, an average weight loss corrosion rate of the steel bar is 0.01-0.04 $g/(m^2 \cdot h)$;

and in simulated concrete pore fluid with the chloride ion concentration greater than or equal to 3 mol/L, a self-corrosion potential of the steel bar is -0.1 V to -0.15 V, a polarization resistance is 2500-3000 $k\Omega/cm^2$, and a self-corrosion current density is less than or equal to 0.13 μA/cm^2.

[0038] Compared with the prior art, the present invention has the following beneficial effects:

(1) On the premise of an ultra-low carbon design, the respective contents and association relationships of Cr, Mo, Mn, Ni and Cu are properly designed, at the same time, the respective contents and association relationships of C, N, Si, Mn and Nb are properly designed, so that the steel bar has a two-phase micro-structure of ferrite and bainite in a reasonable proportion, and the overall comprehensive performance of the steel bar is excellent. Specifically, in an aspect of mechanical performance of the steel bar, a yield strength of the steel bar is greater than or equal to 420 MPa, a tensile strength is greater than or equal to 540 MPa, a percentage elongation after fracture is greater than or equal to 18%, and a maximum force total elongation percentage is greater than or equal to 7.5%. In an aspect of corrosion-resistant performance, in a periodic infiltration corrosion test and a salt mist corrosion test, the corrosion-resistant performance is improved by 45 times or greater through being compared with that of ordinary HRB400. In an electrochemical corrosion test, the positive shift amplitude of the self-corrosion potential relative to the ordinary HRB400 exceeds 0.4 V, a polarization resistance is much greater than that of ordinary HRB400, and a self-corrosion current density equals to 1/65 or even less of that of ordinary HRB400. In an aspect of welding performance, the welding is easy, a welding point structure is firm, breaking cannot easily occur, and a breaking point of a welded sample in a tensile test is formed in a base material position of the two steel bars.

(2) Based on a design scheme of the chemical ingredients, the excellent corrosion-resistant performance, comprehensive mechanical performance and welding performance can be realized, in addition, the cost of alloy elements is low, the energy is saved, the consumption is reduced, the 400 MPa corrosion-resistant steel bar can be prepared through a plurality of process routes, the cost of the production process is reduced, and the present invention is suitable for practical production and processing, and has higher social significance and economic effects.

(3) Additionally, on the premise of a design scheme of the chemical ingredients, in combination with process control in controlled rolling and controlled cooling, the tissue, mechanical performance, corrosion-resistant performance and welding performance of the steel bar can be further optimized, so that the comprehensive performance of the steel bar can be further improved. In addition, the process operation in the hot continuous rolling process can be simple, convenient and easy to control, and the smoothness of the working conditions in practical production is ensured.

DETAILED DESCRIPTION

[0039] The technical solution of the present invention will be further described with reference to specific embodiments, but the protection scope is not limited to the descriptions.

<First embodiment>

[0040] According to this embodiment, a corrosion-resistant steel bar, particularly a hot rolled ribbed steel bar was provided. The steel bar included the following chemical ingredients in percentage by mass: 9.5-10.4% of Cr, 1.0-1.2% of Mo, 0.3-0.6% of Mn, 0.01-1.00% of Ni, 0.01-0.50% of Cu, at most 0.014% of C, at most 0.004% of N, 0.01-0.05% of Nb, 0.2-0.6% of Si, at most 0.004% of S, at most 0.003% of O, at most 0.01% of As, 0.01-0.03% of P, and the balance of Fe and unavoidable impurities.

[0041] Additionally, the mass percentage of Cr, Mo, Mn, Ni and Cu in the chemical ingredients of the steel bar also met: $11.1\% \leq Cr+Mo+0.5Mn+0.35Ni+0.25Cu \leq 12.2\%$, and the mass percentage of C, N, Si, Mn and Nb further met: $0.4\% \leq C+N+0.3Si+Mn+1.8Nb \leq 0.8\%$.

[0042] The effects of each chemical ingredient in the steel bar are as follows:

Cr: it is an important corrosion-resistant element, and capable of forming an oxide passivation film on the surfaces of steel bars to thus effectively prevent the steel bar oxidization and improve the corrosion-resistant capability of matrixes of the steel bars; it can give more excellent corrosion-resistant performance to the steel bars and prevent occurrence of pitting corrosion under the condition of co-existence with elements such as Mo and Ni; and additionally, the element Cr can also improve the hardenability of the steel bars. In the chemical ingredient design of the present invention, the Cr content was controlled to be 9.5-10.4%.

[0043] Mo: it is an important corrosion-resistant element. No matter in a reducing acid environment or a strong oxidizing salt solution environment, by adding the element Mo, the surfaces of the steel bars may be passivated, and the occurrence of pitting corrosion of the steel bars in a chloride solution can be prevented, so that the corrosion-resistant performance of the steel bars in various environments can be integrally improved. Additionally, the inhibition effect of the element Mo on the pearlite conversion is very obvious, and at the same time, in combination with a carbide forming element Cr, the generation of bainite may be promoted; and in addition, the element Mo can promote grain refinement and improve the hardenability and heat resistance of the steel bars. However, when the Mo content is too high, the oxidization resistance of the steel bar may deteriorate. In the chemical ingredient design of the present invention, the Mo content was controlled to be 1.0-1.2%.

[0044] Mn: it is a solid solution strengthening element, can improve the strength of a wire rod, can be combined with a harmful element S to reduce the hot shortness of the steel bars, and is also an important deoxidizing agent, desulfurizing agent and austenite forming element at the same time. However, when the Mn content is too high, the plasticity, impact toughness, welding performance, etc. of the steel bars may all decline. In the chemical ingredient design of the present invention, the Mn content was controlled to be 0.3-0.6%.

[0045] Ni: it is an important corrosion-resistant element, enables the steel bars to achieve higher corrosion-resistant capability to acidic and alkaline environments, and enables the steel bars to achieve higher anti-rust capability and heat-resistant capability at a high temperature; and at the same time, the element Ni is an austenite forming element, and capable of enabling the steel to have uniform austenite tissues to improve the corrosion-resistant performance. In the chemical ingredient design of the present invention, the Ni content was controlled to be 0.01-1.00%.

[0046] Cu: it is an important corrosion-resistant element, and is favorable for improving the corrosion-resistant performance of the steel bars, however, when the Cu content is too high, the plasticity reduction of the steel may be caused, and hot rolling cracking may be caused. In the chemical ingredient design of the present invention, the Cu content was controlled to be 0.01-0.50%.

[0047] C: it is an austenite forming element, by controlling the C content to maintain at a value below a dissolution limit of ferrite, the steel tissue structure and ingredient distribution uniformity can be improved, and the potential difference between all regions inside the steel bars can be reduced, so that the corrosion rate can be reduced. In the chemical ingredient design of the present invention, the C content was controlled to be 0.014% or less.

[0048] N: it is an austenite forming element. If the N content is too high, the plasticity of the steel bars may be reduced, and the too high N content may be unfavorable for the proportion control of ferrite to bainite in steel bar tissues. In the chemical ingredient design of the present invention, the N content was controlled to be 0.004% or less.

[0049] Nb: it is a micro-alloy strengthening element, and can achieve precipitation strengthening and refined crystalline strengthening effects in a rolling process (such as a hot continuous rolling working procedure as mentioned below); and however, too high Nb content may cause plasticity reduction and cost increase of the steel bars. In the chemical ingredient design of the present invention, the Nb content was controlled to be 0.01-0.05%.

[0050] Si: it is a solid solution strengthening element, can achieve solid solution into ferrite, can inhibit the diffusion of the element C in the austenite and delay the phase change of ferrite and pearlite, and can improve the yield strength and tensile strength of the steel bars; and however, too high Si content may reduce the plasticity of the steel and deteriorate the welding performance of the steel bars. In the chemical ingredient design of the present invention, the Si content was controlled to be 0.2-0.6%.

[0051] P: it can improve the strength and corrosion-resistant performance of the steel bars, but may easily generate segregation in steel, and additionally, too high P content may cause poor mechanical performance at a low temperature. In the chemical ingredient design of the present invention, the P content was controlled to be 0.01-0.03%.

[0052] Cr+Mo+0.5Mn+0.35Ni+0.25Cu: it is very important for comprehensive control on the corrosion-resistant performance, plasticity and cost of the steel bars, in one aspect, an oxidation film on the surfaces of the steel bars has the sufficient compactness, the corrosion-resistant repair capability of the matrixes of the steel bars is improved, and the corrosion-resistant performance of the oxidation film of the steel bars and the matrixes of the steel bars is ensured. In another aspect, too low proportion of the ferrite in the steel bar tissues is avoided, the microscopic structure and the proportion of the steel bars are favorably controlled to improve the plasticity of the steel bars, and the percentage elongation after fracture and the maximum force total elongation percentage are increased. In further another aspect, the addition of precious alloy elements is reduced, the cost is reduced, and the engineering promotion, design and use are promoted. In the chemical ingredient design of the present invention, Cr+Mo+0.5Mn+0.35Ni+0.25Cu met 11.1-12.2%.

[0053] C+N+0.3Si+Mn+1.8Nb: it is very important on the comprehensive control of mechanical performance of strength, plasticity, etc. of the steel bars. In one aspect, the alloy element is enabled to sufficiently achieve the respective effects of solid solution strengthening, precipitation strengthening, tissue strengthening, etc. to improve the strength of the steel bars. In another aspect, lower proportion of the ferrite in the steel bar tissues is avoided, higher proportion of the bainite in the steel bar tissues is avoided, the respective proportions of the ferrite and bainite in the steel bar tissues are optimized, the plasticity of the steel bars is improved, and the percentage elongation after fracture and the maximum force total elongation percentage are increased. In the chemical ingredient design of the present invention, C+N+0.3Si+Mn+1.8Nb met 0.4-0.8%.

[0054] Based on the above, compared with the prior art, the present invention had the advantages that in the chemical ingredient design of the present invention: (1) on the premise of an ultra-low carbon design, the respective contents and association relationships of Cr, Mo, Mn, Ni and Cu were properly designed, at the same time, the respective contents and association relationships of C, N, Si, Mn and Nb were properly designed, so that the steel bar had a micro-structure of ferrite and bainite, the proportion of the ferrite was 28%-40%, the proportion of the bainite was 60%-72%, additionally, the steel bar had the excellent corrosion-resistant performance, comprehensive mechanical performance and welding performance, the overall comprehensive performance of the steel bar was excellent, and the steel bar met the use requirements of ocean engineering; and (2) under the condition of a design scheme of the chemical ingredients, the excellent corrosion-resistant performance, comprehensive mechanical performance and welding performance can be realized, in addition, the cost of alloy elements was low, the energy was saved, the consumption was reduced, the 400 MPa corrosion-resistant steel bar can be prepared through a plurality of process routes, the cost of the production process was reduced, and the present invention was suitable for practical production and processing, and had higher social significance and economic effects.

[0055] As mentioned above, the micro-structure of the steel bar was ferrite and bainite, the ferrite accounted for 28%-40%, and the bainite accounted for 60%-72%. Therefore, the influence of the micro-structure and the proportions of the ferrite and bainite of the micro-structure on the steel bar was further embodied in two aspects: the first aspect was the mechanical performance, the proper yield strength and good percentage elongation including the percentage elongation after fracture and the maximum force total elongation percentage can be ensured through the proportion control of the ferrite and bainite in this embodiment, and the good comprehensive mechanical performance was ensured. The other aspect was the corrosion-resistant performance, and the corrosion-resistant performance of the steel bar can be improved by ensuring a certain bainite tissue proportion.

[0056] Specifically, in an aspect of the mechanical performance, the steel bar was a 400 MPa or greater steel bar with a yield strength greater than or equal to 420 MPa, a tensile strength greater than or equal to 540 MPa, a percentage elongation after fracture greater than or equal to 18%, and a maximum force total elongation percentage greater than or equal to 7.5%.

[0057] Additionally, the steel bar was well controlled in an aspect of inclusions. Specifically, An A-type inclusion, B-type inclusion, C-type inclusion and D-type inclusion of the steel bar at the standard of GB/T10561 were all less than or equal to 1.0 level. Therefore, the toughness of the steel bar under the low-temperature condition can be improved, and the mechanical performance of the steel bar was favorably ensured.

[0058] Further, in an aspect of corrosion-resistant performance, in a periodic infiltration corrosion test and a salt mist corrosion test, the corrosion-resistant performance was improved by 45 times or greater through being compared with that of ordinary HRB400. Specifically, in the periodic infiltration corrosion test, an average weight loss corrosion rate of the steel bar was 0.05-0.1 g/($m^2 \cdot h$); and in the salt mist corrosion test, an average weight loss corrosion rate of the steel bar was 0.01-0.04 g/($m^2 \cdot h$);

and in simulated concrete pore fluid with the chloride ion concentration greater than or equal to 3 mol/L, a self-corrosion potential of the steel bar was -0.1 V to -0.15 V, a polarization resistance was 2500-3000 kΩ/cm^2, and a self-corrosion current density was less than or equal to 0.13 μA/cm^2.

[0059] A specific method of the used periodic infiltration corrosion test was as follows: a treated sample was put into a periodic infiltration test tank, the test was performed according to a corrosion test method of a YB/T4367 steel bar in a chloride ion environment, a solution was 2.0$\pm$0.05(wt%) NaCl, a pH value was 6.5-7.2, a temperature of the solution was 45°C$\pm$2°C, a drying temperature was 70°C$\pm$10°C, the test was continuously performed, and an average weight loss corrosion rate at 168 h was obtained.

[0060] A specific method of the used salt mist corrosion test was as follows: a treated sample was put into a salt mist test tank, the test was performed according to a GB/T10125 artificial atmosphere corrosion test-salt mist corrosion test, a solution was 2.0$\pm$0.05(wt%) NaCl, a pH value was 6.5-7.2, a temperature of the solution was 35°C$\pm$2°C, the test was continuously performed, and an average weight loss corrosion rate at 168 h was obtained.

[0061] In an electrochemical corrosion test, under a corrosion test condition of simulated concrete pore fluid with the chloride ion concentration greater than or equal to 3 mol/L, a self-corrosion potential of the steel bar was -0.1 V to -0.15 V, and the positive shift amplitude relative to the ordinary HRB400 exceeded 0.4 V; a polarization resistance of the steel bar was 2500-3000 kΩ/cm^2, and was much greater than that of ordinary HRB400; and a self-corrosion current density of the steel bar was equal to or less than 0.13 μA/cm^2, and equaled to 1/65 or even less of that of ordinary HRB400.

[0062] A specific method of the used electrochemical corrosion test was as follows: the electrochemical corrosion test was performed according to GB/T24196-2009 "Corrosion of metals and alloys-Electrochemical test methods-Guidelines for conducting potentiostatic and potentiodynamic polarization measurements", a three-electrode system was used, a reference electrode was a saturated calomel electrode, an auxiliary electrode was a Pt sheet, and a test solution was a simulated concrete pore fluid with the chloride ion concentration greater than or equal to 3 mol/L; a polarization curve test scanning range was -300 mV to 600 mV relative to the sample self-corrosion potential, and a scanning frequency was 1 mV/s; and an electrochemical impedance test scanning frequency range was 10^{-2}-10^5 Hz, and an alternating current excitation signal amplitude value was $\pm$5 mV.

[0063] Therefore, in an aspect of the corrosion-resistant performance, the steel bar had excellent corrosion-resistant performance, and under the condition of performing the corrosion performance test in a simulated sea water solution, each index was much better than that of an ordinary thread steel bar of the same level.

[0064] In an aspect of the welding performance, the steel bar was easy to weld. When the two steel bars were connected into a welded sample through electric slag pressure welding, a welding point structure was firm, breaking cannot easily occur, a breaking point of the welded sample in a tensile test was formed in a base material position of the two steel bars instead of a welding point position.

[0065] Preferably, in this embodiment, a nominal diameter of the steel bar was 6-32 mm.

[0066] When the nominal diameter of the steel bar was 6-10 mm, the steel bar was made into a coiled steel bar; and when the nominal diameter of the steel bar was 12-32 mm, the steel bar was made into a straight steel bar. Therefore, the requirement of ocean engineering on the steel bar can be met. Additionally, through the design of the diameter, the comprehensive mechanical performance and corrosion-resistant performance of the steel bar structure can be improved.

<Second embodiment>

[0067] According to this embodiment, a corrosion-resistant steel bar was provided, and was particularly a hot rolled ribbed steel bar suitable for ocean engineering. The corrosion-resistant steel bar mainly differed from the first embodiment in that: any one or more of 0.1-0.15% of V, 0.01-0.05% of Ti, 0.01-0.03% of Al and 0.0005-0.0020% of B were further added to chemical ingredients to further improve the performance of the steel bar.

[0068] Specifically, in this embodiment, the steel bar included the following ingredients in percentage by mass: 9.5-10.4% of Cr, 1.0-1.2% of Mo, 0.3-0.6% of Mn, 0.01-1.00% of Ni, 0.01-0.50% of Cu, at most 0.014% of C, at most 0.004% of N, 0.01-0.05% of Nb, 0.2-0.6% of Si, at most 0.004% of S, at most 0.003% of O, at most 0.01% of As, 0.01-0.03% of P, any one of 0.1-0.15% of V, 0.01-0.05% of Ti, 0.01-0.03% of Al and 0.0005-0.0020% of B, and the balance of Fe and unavoidable impurities.

[0069] In addition, the same as the first embodiment, the mass percentage of Cr, Mo, Mn, Ni and Cu in the chemical ingredients of the steel bar also met: $11.1\% \leq Cr+Mo+0.5Mn+0.35Ni+0.25Cu \leq 12.2\%$, and the mass percentage of C, N, Si, Mn and Nb further met: $0.4\% \leq C+N+0.3Si+Mn+1.8Nb \leq 0.8\%$.

[0070] The effects of elements such as Cr, Mo, Mn, Ni, Cu, C, N, Nb, Si, and P in the steel bar and the design effects of Cr+Mo+0.5Mn+0.35Ni+0.25Cu and C+N+0.3Si+Mn+1.8Nb are the same as those in the first embodiment, and will not be repeated herein. The effects of optional elements V, Ti, Al and B in this embodiment will be illustrated hereafter.

[0071] V: it is a microalloy strengthening element, can achieve precipitation of V (C, N) compounds in a rolling process (such as a hot continuous rolling working procedure as mentioned below), has a certain precipitation strengthening effect, can prevent austenite and ferrite crystalline grains from growing, and has a refined crystalline strengthening effect; and however, too high V content may cause plasticity reduction and cost increase of the steel bar. In the chemical ingredient design of the present invention, the V content was controlled to be 0.1-0.15%.

[0072] Ti: it has higher affinity than Cr, so that the occurrence of grain boundary chromium depletion due to chromium carbide precipitation can be avoided, so that the inter-crystalline corrosion is effectively prevented; in addition, by adding a proper amount of Ti, fine TiO_x and TiN in dispersed distribution can be formed in a steel plate; and however, too high Ti content may increase the viscosity of the molten steel, is unfavorable for the melting of the molten steel, and may also cause the course size of the formed TiO_x and deteriorate the toughness of the steel plate at the same time. In the chemical ingredient design of the present invention, the Ti content was controlled to be 0.01-0.05%.

[0073] Al: it is a common deoxidizing agent, and can improve the electrode potential of the matrix of the steel bar, improve the corrosion-resistant performance and prevent austenite crystalline grains from growing to improve the strength of the steel bar; however, too high Al content may cause increase of oxides in the steel, and is unfavorable for the welding performance of the steel bar. In the chemical ingredient design of the present invention, the Al content was controlled to be 0.01-0.03%.

[0074] B: it is a strengthening element, has a significant effect on improving the strength of the steel bar, but too high B content is unfavorable for the improvement of the inter-crystalline corrosion-resistant performance. In the chemical ingredient design of the present invention, the B content was controlled to be 0.0005-0.0020%.

[0075] In this present embodiment, based on the optional addition of any one or more of V, Ti, Al and B, the performance of the steel bar may be further improved based on the first embodiment, the steel bar had the excellent corrosion-resistant performance, mechanical performance, plasticity and welding performance, the engineering construction was convenient, and the steel bar may achieve a longer theoretical service life when being used in ocean engineering.

<Third embodiment>

[0076] According to this embodiment, a production method of a corrosion-resistant steel bar was provided. The production method may be used for producing and preparing the corrosion-resistant steel bar according to the first embodiment, and may be used for producing and preparing the corrosion-resistant steel bar according to the second embodiment.

[0077] According to this embodiment, a process route of the production method included a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an AOD furnace refining working procedure, an LF furnace refining working procedure, a square billet continuous casting working procedure, a hot continuous rolling working procedure, a temperature-controlled cooling working procedure and a packing working procedure which were performed in sequence. The production method will be described below in detail according to the step sequence.

(1) A steel making step:

[0078] In this step, a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an AOD furnace refining working procedure and an LF furnace refining working procedure were sequentially adopted for molten steel melting, and the obtained molten steel was continuously cast into steel billets through the square billet continuous casting working procedure.

[0079] It can be understood that when the used production method was used for preparing the corrosion-resistant steel bar according to the first embodiment, the chemical ingredients of the steel billets obtained in this step were the same as the chemical ingredients of the steel bar according to the first embodiment. That was, the steel billets included the following chemical ingredients in percentage by mass: 9.5-10.4% of Cr, 1.0-1.2% of Mo, 0.3-0.6% of Mn, 0.01-1.00% of Ni, 0.01-0.50% of Cu, at most 0.014% of C, at most 0.004% of N, 0.01-0.05% of Nb, 0.2-0.6% of Si, at most 0.004% of S, at most 0.003% of O, at most 0.01% of As, 0.01-0.03% of P, and the balance of Fe and unavoidable impurities, and in addition, Cr+Mo+0.5Mn+0.35Ni+0.25Cu was 11.1-12.2%, and C+N+0.3Si+Mn+1.8Nb was 0.4-0.8. Similarly, when the production method was used for preparing the corrosion-resistant steel bar according to the second embodiment, the chemical ingredients of the steel billets in the step were the same as the chemical ingredients of the steel bar according to the second embodiment. That was, the steel billets included the following chemical ingredients in percentage by mass: 9.5-10.4% of Cr, 1.0-1.2% of Mo, 0.3-0.6% of Mn, 0.01-1.00% of Ni, 0.01-0.50% of Cu, at most 0.014% of C, at most 0.004% of N, 0.01-0.05% of Nb, 0.2-0.6% of Si, at most 0.004% of S, at most 0.003% of O, at most 0.01% of As, 0.01-0.03% of P, any one or more of 0.1-0.15% of V, 0.01-0.05% of Ti, 0.01-0.03% of Al and 0.0005-0.0020% of B, and the balance of Fe and unavoidable impurities, and in addition, Cr+Mo+0.5Mn+0.35Ni+0.25Cu was 11.1-12.2%, and C+N+0.3Si+Mn+1.8Nb was 0.4-0.8.

[0080] Further, a tapping temperature of the converter smelting working procedure was 1600-1660°C, the decarburization and dephosphorization effects were ensured, and the subsequent alloying was facilitated.

[0081] In the AOD furnace refining working procedure, by overall consideration, low-cost high-carbon ferro-chrome alloy and ferro-molybdenum alloy were added into molten steel to realize preliminary alloying on the molten steel, slagging-off was performed after reduction, the contents of impurity contents such as P can be reduced, then, manganese alloy was added, and preliminary alloying was completed at the same time of deoxygenation. Before tapping, a steel ladle for tapping was purged by argon gas for 5 min or a longer time, secondary oxidization of the molten steel was reduced. 20 kg of aluminum ingots were added into the molten steel in the tapping process, a tapping temperature was 1630-1670°C, and a tapping C content was less than or equal to 0.01%, and a molten steel decarburization effect and a production rhythm were ensured.

[0082] In the LF furnace refining working procedure, after the molten steel reached the steel ladle of an LF furnace, slag regulation was performed according to a scheme of adding 13-15 kg of lime and 4.0-6.5 kg of fluorite into per ton of molten steel, a white slag maintaining time was greater than or equal to 8 min, a soft stirring time was 8-15 min, a tapping temperature was 1600-1620°C, and the molten steel deoxidization and desulfuration were completed step by step.

[0083] In the square billet continuous casting working procedure, tapping molten steel of the LF furnace refining working procedure was made into square billets through continuous casting. Carbon-free protection slag or ultra-low-carbon protection slag was used to prevent carbon content increase in the molten steel, a continuous casting temperature was 1520-1560°C, a drawing speed in the continuous casting process was 1.2-1.6 m/min, and continuous casting was ensured.

(2) Controlled rolling and controlled cooling:

[0084] In this step, the steel billets obtained in Step (1) were rolled into steel bars with a nominal diameter of 6-32 mm through a hot continuous rolling working procedure, and then, a temperature-controlled cooling working procedure was performed. According to different nominal diameters of the steel bars, the specific process schemes of this step were different.

[0085] Specifically, for the steel bars with the nominal diameter of 12-32 mm, in this step: in the hot continuous rolling working procedure, the steel billets obtained in Step (1) were heated in a heating furnace at a heating temperature of 1100-1200°C for an in-furnace time of 60-120 min, alloy elements were sufficiently redissolved, and the strengthening effects of the alloy elements were facilitated. Then, the steel billets were rolled into straight thread steel bars with a diameter of 12-32 mm at an initial rolling temperature of 1000-1100°C and a finish rolling temperature of 850-950°C, so that austenite crystalline grains were maintained at a certain size. Then, in the temperature-controlled cooling working procedure, the rolled straight thread steel bars were naturally cooled on a cooling bed at a temperature on the cooling bed of 860-920°C, and the subsequent ferrite and pearlite size and proportion control were ensured.

[0086] For the steel bars with the nominal diameter of 6-10 mm, in this step: in the hot continuous rolling working procedure, the steel billets obtained in Step (1) were heated in a heating furnace at a heating temperature of 1080-1130°C, sufficient redissolution of alloy elements was facilitated, and the in-furnace time was 60-120 min. Then, the steel billets were rolled into coiled thread steel bars with a diameter of 6-10 mm at an initial rolling temperature of 980-1030°C, a finish rolling temperature of 850-950°C and a spinning temperature of 830-920°C, so that austenite crystalline grains were maintained at a certain size. Then, in the temperature-controlled cooling working procedure, the rolled coiled thread steel bars were cooled in a delayed Stelmor cooling manner while all fans under a roller bed were turned off, and the phase change of ferrite and pearlite was completed on the roller bed.

(3) Packing:

[0087] The steel bars cooled in Step (2) were packed to be transported and put into engineering application.
[0088] Therefore, compared with the prior art, the production method according to this embodiment had the following beneficial effects:

(1) For the chemical ingredient design, on the premise of an ultra-low carbon design, the respective contents and association relationships of Cr, Mo, Mn, Ni and Cu were properly designed, at the same time, the respective contents and association relationships of C, N, Si, Mn and Nb were properly designed, so that the prepared steel bar had a micro-structure of ferrite and bainite while the ferrite accounted for 28%-40% and the bainite accounted for 60%-72%, in addition, the steel bar had the excellent corrosion-resistant performance, comprehensive mechanical performance and welding performance, had excellent overall comprehensive performance, and met the use requirements of ocean engineering.
(2) Under the condition of the above design scheme of the chemical ingredients, the process route was reasonable. Particularly, the process control in the controlled rolling and controlled cooling was reasonable. The overall comprehensive performance was further optimized, and no crack defect existed in the rolling process. In addition, the cost of alloy elements was low, the energy was saved, the consumption was reduced, the cost of the production process was reduced, the method was suitable for practical production and processing, the process operation was simple, convenient and easy to control, the smoothness of the working conditions in practical production was ensured, and higher social significance and economic effects were achieved.

<Fourth embodiment>

[0089] According to this embodiment, a production method of a corrosion-resistant steel bar was provided. The production method may be used for producing and preparing the corrosion-resistant steel bar according to the first embodiment, and may be used for producing and preparing the corrosion-resistant steel bar according to the second embodiment.
[0090] According to this embodiment, the process route of the production method included a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an LF furnace refining working procedure, an RH furnace refining working procedure, a square billet continuous casting working procedure, a hot continuous rolling working procedure, a temperature-controlled cooling working procedure and a packing working procedure which were performed in sequence. That was, this embodiment mainly differed from the third embodiment in: the molten iron pre-desulfuration working procedure, the converter smelting working procedure, the LF furnace refining working procedure, the RH furnace refining working procedure and the square billet continuous casting working procedure, i.e., the steel making steps. The production method according to this embodiment will be described in detail hereafter only in aspects of the steel making steps.

(1) A steel making step:

[0091] In this step, a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an LF furnace refining working procedure and an RH furnace refining working procedure were sequentially adopted for molten steel melting, and the obtained molten steel was continuously cast into steel billets through the square billet continuous casting working procedure.
[0092] It can be understood that when the used production method was used for preparing the corrosion-resistant steel bar according to the first embodiment, the chemical ingredients of the steel billets obtained in this step were the same as the chemical ingredients of the steel bar according to the first embodiment. That was, the steel billets included the following chemical ingredients in percentage by mass: 9.5-10.4% of Cr, 1.0-1.2% of Mo, 0.3-0.6% of Mn, 0.01-1.00% of Ni, 0.01-0.50% of Cu, at most 0.014% of C, at most 0.004% of N, 0.01-0.05% of Nb, 0.2-0.6% of Si, at most 0.004% of S, at most 0.003% of O, at most 0.01% of As, 0.01-0.03% of P, and the balance of Fe and unavoidable impurities,

and in addition, Cr+Mo+0.5Mn+0.35Ni+0.25Cu was 11.1-12.2%, and C+N+0.3Si+Mn+1.8Nb was 0.4-0.8. Similarly, when the production method was used for preparing the corrosion-resistant steel bar according to the second embodiment, the chemical ingredients of the steel billets in the step were the same as the chemical ingredients of the steel bar according to the second embodiment. That was, the steel billets included the following chemical ingredients in percentage by mass: 9.5-10.4% of Cr, 1.0-1.2% of Mo, 0.3-0.6% of Mn, 0.01-1.00% of Ni, 0.01-0.50% of Cu, at most 0.014% of C, at most 0.004% of N, 0.01-0.05% of Nb, 0.2-0.6% of Si, at most 0.004% of S, at most 0.003% of O, at most 0.01% of As, 0.01-0.03% of P, any one or more of 0.1-0.15% of V, 0.01-0.05% of Ti, 0.01-0.03% of Al and 0.0005-0.0020% of B, and the balance of Fe and unavoidable impurities, and in addition, Cr+Mo+0.5Mn+0.35Ni+0.25Cu was 11.1-12.2%, and C+N+0.3Si+Mn+1.8Nb was 0.4-0.8.

[0093] Further, in the converter smelting working procedure, micro-carbon ferro-chrome alloy was added into molten steel in a tapping process to realize preliminary alloying on the molten steel, the C content in the molten steel was possibly controlled from an alloy adding perspective, the efficiency was improved, a tapping temperature was 1700-1750°C, a dephosphorization effect was ensured, and good preparation was prepared for subsequent melting.

[0094] In the LF furnace refining working procedure, a steel ladle in an LF furnace was subjected to whole-process bottom blowing at an argon gas flow rate of 80-160 L/min, and a tapping temperature was 1560-1600°C. The dissolution and homogenization of alloy in the steel ladle were ensured, and a production rhythm was facilitated.

[0095] In the RH furnace refining working procedure, after vacuum pumping on an RH furnace for 3 min, oxygen was started to be blown into the RH furnace, a total oxygen blowing amount was 500-700 Nm^3, then, micro-carbon ferro-chrome alloy was added into molten steel to realize alloying on the molten steel, Cr alloying was completed in steps, and at the same time, the carbon content increase of the molten steel was reduced. Clean circulation treatment was performed for 5 min or a longer time when a vacuum degree was less than 2 mbar, a tapping temperature was 1560-1600°C, and a tapping C content was less than or equal to 0.015% to ensure the decarburization effect.

[0096] In the square billet continuous casting working procedure, tapping molten steel in the LF furnace refining working procedure was continuously cast into square billets. Carbon-free protection slag or ultra-low-carbon protection slag was used, the carbon content increase of the molten steel was prevented, a continuous casting temperature was 1520-1560°C, a drawing speed in the continuous casting process was 2.2-2.6 m/min, and continuous casting was facilitated.

[0097] As mentioned above, the controlled rolling and controlled cooling step in Step (2) and the packing working procedure in Step (3) were all the same as those of the third embodiment, and will not be repeated.

[0098] Therefore, compared with the prior art, the production method according to this embodiment had the following beneficial effects:

(1) For the chemical ingredient design, on the premise of an ultra-low carbon design, the respective contents and association relationships of Cr, Mo, Mn, Ni and Cu were properly designed, at the same time, the respective contents and association relationships of C, N, Si, Mn and Nb were properly designed, so that the prepared steel bar had a micro-structure of ferrite and bainite while the ferrite accounted for 28%-40% and the bainite accounted for 60%-72%, in addition, the steel bar had the excellent corrosion-resistant performance, comprehensive mechanical performance and welding performance, had excellent overall comprehensive performance, and met the use requirements of ocean engineering.

(2) Under the condition of the above design scheme of the chemical ingredients, the process route was reasonable. Particularly, the process control in the controlled rolling and controlled cooling was reasonable. The overall comprehensive performance was further optimized, and no crack defect existed in the rolling process. In addition, the cost of alloy elements was low, the energy was saved, the consumption was reduced, the cost of the production process was reduced, the method was suitable for practical production and processing, the process operation was simple, convenient and easy to control, the smoothness of the working conditions in practical production was ensured, and higher social significance and economic effects were achieved.

<Fifth embodiment>

[0099] According to this embodiment, a production method of a corrosion-resistant steel bar was provided. A process route of the production method included a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an LF furnace refining working procedure, an RH furnace refining working procedure, a square billet continuous casting working procedure, a hot continuous rolling working procedure, a temperature-controlled cooling working procedure, an on-line acid pickling working procedure and a packing working procedure which are performed in sequence.

[0100] In this embodiment, from the molten iron pre-desulfuration working procedure to the temperature-controlled cooling working procedure, the above-mentioned third embodiment can be adopted, and the above-mentioned fourth embodiment can also be adopted, that was, according to this embodiment, based on the above-mentioned third embodiment or fourth embodiment, the on-line acid pickling working procedure was added before the packing working procedure. Only the on-line acid pickling working procedure will be described below, and other details are not described again.

[0101] Specifically, in the on-line acid pickling working procedure, that was, after the temperature-controlled cooling working procedure and before the packing working procedure, the steel bar sequentially passed through an acid pickling tank, a passivation tank and a drying device to realize on-line acid pickling of the steel bar. Gas jet holes of the acid pickling tank were distributed around a center line of the acid pickling tank to enhance the acid pickling effect.

[0102] Examples 1-16 of the present invention will be provided below for further illustrating the present invention. It shall be understood that the following are only some of the exemplary examples of the present invention, not all examples of the present invention, and other examples made on the basis of the foregoing examples will not depart from the spirit of the present invention.

[0103] Firstly, each of Examples 1-16 and Comparative examples 1-4 provided a steel bar, and chemical ingredients of the steel bar were as shown in Table 1. Example 12 was implemented according to the first embodiment of the present invention. Other Examples were implemented according to the second embodiment of the present invention. Comparative examples 1-4 did not meet any embodiment of the present invention.

[Table 1]

	Chemical ingredients in percentage by mass (wt, %)																
	Cr	Mo	Mn	Ni	Cu	C	N	Nb	Si	S	O	As	P	V	Ti	Al	B
Example 1	9.53	1.02	0.44	0.92	0.08	0.013	0.0039	0.017	0.59	0.002	0.003	0.006	0.015	0.15	0.05	0.03	0.0020
Example 2	9.52	1.02	0.32	0.06	0.29	0.014	0.0020	0.014	0.20	0.004	0.001	0.005	0.012	0.13	0.01	0.04	0.0005
Example 3	9.50	1.20	0.36	0.97	0.13	0.014	0.0020	0.010	0.42	0.002	0.001	0.005	0.017	0.15	-	0.03	-
Example 4	9.61	1.19	0.38	0.74	0.19	0.013	0.0033	0.017	0.24	0.003	0.003	0.008	0.010	0.14	0.02	0.03	0.0017
Example 5	10.17	1.00	0.33	0.75	0.09	0.010	0.0035	0.050	0.55	0.002	0.003	0.008	0.024	0.12	-	-	-
Example 6	9.56	1.06	0.55	0.45	0.31	0.014	0.0040	0.049	0.31	0.003	0.002	0.008	0.029	-	-	0.02	-
Example 7	9.68	1.20	0.49	0.27	0.29	0.012	0.0034	0.036	0.28	0.004	0.002	0.009	0.021	-	0.02	-	0.0007
Example 8	10.30	1.13	0.48	0.01	0.11	0.014	0.0022	0.013	0.23	0.003	0.002	0.008	0.019	0.14	-	0.02	-
Example 9	10.40	1.17	0.30	0.60	0.04	0.010	0.0039	0.011	0.22	0.001	0.001	0.004	0.023	-	0.04	-	0.0013
Example 10	9.67	1.02	0.57	0.95	0.29	0.013	0.0021	0.019	0.60	0.003	0.002	0.006	0.010	0.11	-	0.04	-
Example 11	9.64	1.05	0.39	0.53	0.49	0.012	0.0023	0.025	0.52	0.003	0.002	0.008	0.024	-	0.03	-	0.0008
Example 12	10.05	1.14	0.57	0.46	0.29	0.011	0.0031	0.033	0.29	0.003	0.002	0.008	0.015	-	-	-	-
Example 13	9.69	1.05	0.59	0.89	0.50	0.012	0.0036	0.020	0.29	0.002	0.002	0.004	0.030	0.15	0.05	0.02	0.0013
Example 14	10.03	1.17	0.60	0.54	0.50	0.012	0.0025	0.021	0.47	0.003	0.002	0.007	0.020	-	0.01	-	
Example 15	10.15	1.20	0.31	1.00	0.49	0.011	0.0037	0.039	0.46	0.004	0.001	0.004	0.011	-	-	-	0.0008
Example 16	10.25	1.18	0.49	0.99	0.47	0.014	0.0024	0.012	0.52	0.003	0.001	0.004	0.020	0.10	0.03	0.01	0.0008
Comparative example 1	-	-	1.37	-	-	0.024	0.0070	0.002	0.47	0.007	0.006	0.010	0.009	0.01	-	0.01	-
Comparative example 2	-	-	1.42	-	-	0.022	0.0064	0.003	0.54	0.006	0.005	0.012	0.009	-	0.02	-	0.0005
Comparative example 3	-	-	1.35	-	-	0.023	0.0065	0.004	0.55	0.005	0.004	0.011	0.013	0.03	-	0.01	-
Comparative example 4	-	-	1.40	-	-	0.025	0.0051	0.003	0.51	0.005	0.006	0.011	0.013	-	0.01	-	0.0004

[0104] The production method according to Examples 1-8 adopted a process route of sequentially performing a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an AOD furnace refining working procedure, an LF furnace refining working procedure, a square billet continuous casting working procedure, a hot continuous rolling working procedure, a temperature-controlled cooling working procedure and an on-line acid pickling working procedure. Each working procedure will be described hereafter.

(1) Molten iron pre-desulfuration working procedure: pre-desulfuration was performed on molten iron.
(2) Converter smelting working procedure: a tapping temperature was 1600-1660°C.
(3) AOD furnace refining working procedure: high-carbon ferro-chrome alloy and ferro-molybdenum alloy were added into molten steel to realize preliminary alloying on the molten steel, slagging-off was performed after reduction, then, manganese alloy was added, before tapping, a steel ladle for tapping was purged by argon gas for 5 min or a longer time, 20 kg of aluminum ingots were added into the molten steel in the tapping process, a tapping temperature was 1630-1670°C, and a tapping C content was less than or equal to 0.010%.
(4) LF furnace refining working procedure: after the molten steel reached the steel ladle of an LF furnace, slag regulation was performed according to a scheme of adding 13-15 kg of lime and 4.0-6.5 kg of fluorite into per ton of molten steel, a white slag maintaining time was greater than or equal to 8 min, a soft stirring time was 8-15 min, and a tapping temperature was 1600-1620°C.
(5) Square billet continuous casting working procedure: tapping molten steel in the LF furnace refining working procedure was continuously cast into square billets, carbon-free protection slag or ultra-low-carbon protection slag was used, a continuous casting temperature was 1520-1560°C, and a drawing speed in the continuous casting process was 1.2-1.6 m/min.
(6) Hot continuous rolling working procedure: in Examples 1-4, the square billets were heated in a heating furnace at a heating temperature of 1100-1200°C for an in-furnace time of 60-120 min, and were then rolled into straight thread steel bars with a diameter of 12-32 mm at an initial rolling temperature of 1000-1100°C and a finish rolling temperature of 850-950°C; and in Examples 5-8, the square billets were heated in a heating furnace at a heating temperature of 1080-1130°C for an in-furnace time of 60-120 min, and were then rolled into coiled thread steel bars with a diameter of 6-10 mm at an initial rolling temperature of 980-1030°C, a finish rolling temperature of 850-950°C and a spinning temperature of 830-920°C.
(7) Temperature-controlled cooling working procedure: in Examples 1-4, the rolled straight thread steel bars were naturally cooled on a cooling bed at a temperature on the cooling bed of 860-920°C; and in Examples 5-8, the rolled coiled thread steel bars were cooled in a delayed Stelmor cooling manner while all fans under a roller bed were turned off.
(8) On-line acid pickling working procedure: the steel bars sequentially passed through an acid pickling tank, a passivation tank and a drying device to realize the on-line acid pickling of the steel bars. Gas jet holes of the acid pickling tank were distributed around a center line of the acid pickling tank. Then, packing was performed.

[0105] The production method according to Examples 9-16 adopted a process route of sequentially performing a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an LF furnace refining working procedure, an RH furnace refining working procedure, a square billet continuous casting working procedure, a hot continuous rolling working procedure, a temperature-controlled cooling working procedure and an on-line acid pickling working procedure. Each working procedure will be described hereafter.

(1) Molten iron pre-desulfuration working procedure: pre-desulfuration was performed on molten iron. After desulfuration, the S content was less than or equal to 0.001%, and a slagging-off rate was greater than or equal to 95%.
(2) Converter smelting working procedure: micro-carbon ferro-chrome alloy was added into molten steel in the tapping process to realize preliminary alloying on the molten steel, and a tapping temperature was 1700-1750°C.
(3) LF furnace refining working procedure: a steel ladle in an LF furnace was subjected to whole-process bottom blowing at an argon gas flow rate of 80-160 L/min, and a tapping temperature was 1560-1600°C.
(4) RH furnace refining working procedure: after vacuum pumping on an RH furnace for 3 min, oxygen was started to be blown into the RH furnace, a total oxygen blowing amount was 500-700 Nm^3, then, micro-carbon ferro-chrome alloy was added into molten steel to realize alloying on the molten steel, clean circulation treatment was performed for 5 min or a longer time when a vacuum degree was less than 2 mbar, a tapping temperature was 1560-1600°C, and a tapping C content was less than or equal to 0.015%.
(5) Square billet continuous casting working procedure: tapping molten steel of the LF furnace refining working procedure was made into square billets through continuous casting, carbon-free protection slag or ultra-low-carbon protection slag was used, a continuous casting temperature was 1520-1560°C, and a drawing speed in the continuous casting process was 2.2-2.6 m/min.
(6) Hot continuous rolling working procedure: in Examples 9-12, the square billets were heated in a heating furnace

at a heating temperature of 1100-1200°C for an in-furnace time of 60-120 min, and were then rolled into straight thread steel bars with a diameter of 12-32 mm at an initial rolling temperature of 1000-1100°C and a finish rolling temperature of 850-950°C; and in Examples 13-16, the square billets were heated in a heating furnace at a heating temperature of 1080-1130°C for an in-furnace time of 60-120 min, and were then rolled into coiled thread steel bars with a diameter of 6-10 mm at an initial rolling temperature of 980-1030°C, a finish rolling temperature of 850-950°C and a spinning temperature of 830-920°C.

(7) Temperature-controlled cooling working procedure: in Examples 9-12, the rolled straight thread steel bars were naturally cooled on a cooling bed at a temperature on the cooling bed of 860-920°C; and in Examples 13-16, the rolled coiled thread steel bars were cooled in a delayed Stelmor cooling manner while all fans under a roller bed were turned off.

(8) On-line acid pickling working procedure: the steel bars sequentially passed through an acid pickling tank, a passivation tank and a drying device to realize the on-line acid pickling of the steel bars. Gas jet holes of the acid pickling tank were distributed around a center line of the acid pickling tank. Then, packing was performed.

[0106] The production method adopted by Comparative examples 1-4 was conventional process route of converter smelting, square billet continuous casting, hot continuous rolling and cooling bed cooling. In the hot continuous rolling working procedure, a heating temperature in the heating furnace was 1210-1290°C, an initial rolling temperature was 1090-1170°C, a temperature on a cooling bed was greater than or equal to 1100°C, and natural cooling was performed on the cooling bed.

[0107] The steel bars according to Examples 1-16 and Comparative examples 1-4 were sampled according to the same test method, and were subjected to mechanical performance detection. The mechanical performance of each example and comparative example was as shown in Table 2.

[0108] From Table 2, it can be seen that Examples 1-16 were obviously superior to Comparative examples 1-4 in aspects of the mechanical performance, they met 400 MPa aseismic steel bar requirements, in addition, the yield strength was greater than or equal to 420 MPa, the tensile strength was greater than or equal to 540 MPa, the percentage elongation after fracture was greater than or equal to 18%, and the maximum force total elongation percentage was greater than or equal to 7.5%.

[Table 2]

Serial number	Yield strength (MPa)	Tensile strength (MPa)	Percentage elongation A after fracture (%)	Maximum force total elongation percentage Agt (%)
Example 1	474	638	25	8.1
Example 2	467	604	20	11.1
Example 3	459	596	20	10.6
Example 4	450	584	21	10.5
Example 5	445	582	21	10.1
Example 6	445	579	20	9.9
Example 7	445	575	20	9.6
Example 8	441	564	21	8.2
Example 9	420	555	18	7.6
Example 10	492	627	24	15.9
Example 11	480	626	24	14.8
Example 12	478	621	22	14.2
Example 13	466	615	22	13.9
Example 14	463	613	22	12.6
Example 15	461	612	20	12.1
Example 16	455	610	20	11.3
Comparative example 1	427	567	19	7.1

(continued)

Serial number	Yield strength (MPa)	Tensile strength (MPa)	Percentage elongation A after fracture (%)	Maximum force total elongation percentage Agt (%)
Comparative example 2	451	555	15	6.9
Comparative example 3	448	578	15	8.9
Comparative example 4	469	594	18	12.3

[0109] The steel bars according to Examples 1-16 and Comparative examples 1-4 were subjected to a periodic infiltration corrosion test, a salt mist corrosion test and an electrochemical corrosion test according to the same method, and the test results were as shown in Table 3.

[0110] A specific method of the used periodic infiltration corrosion test was as follows: a treated sample was put into a periodic infiltration test tank, the test was performed according to a corrosion test method of a YB/T4367 steel bar in a chloride ion environment, a solution was 2.0±0.05(wt%) NaCl, a pH value was 6.5-7.2, a temperature of the solution was 45°C±2°C, a drying temperature was 70°C±10°C, the test was continuously performed, and an average weight loss corrosion rate at 168 h was obtained.

[0111] A specific method of the used salt mist corrosion test was as follows: a treated sample was put into a salt mist test tank, the test was performed according to a GB/T10125 artificial atmosphere corrosion test-salt mist corrosion test, a solution was 2.0±0.05(wt%) NaCl, a pH value was 6.5-7.2, a temperature of the solution was 35°C±2°C, the test was continuously performed, and an average weight loss corrosion rate at 168 h was obtained.

[0112] A specific method of the used electrochemical corrosion test was as follows: the electrochemical corrosion test was performed according to GB/T24196-2009 "Corrosion of metals and alloys-Electrochemical test methods-Guidelines for conducting potentiostatic and potentiodynamic polarization measurements", a three-electrode system was used, a reference electrode was a saturated calomel electrode, an auxiliary electrode was a Pt sheet, and a test solution was a simulated concrete pore fluid with the chloride ion concentration greater than or equal to 3 mol/L; a polarization curve test scanning range was -300 mV to 600 mV relative to the sample self-corrosion potential, and a scanning frequency was 1 mV/s; and an electrochemical impedance test scanning frequency range was 10^{-2}-10^{5} Hz, and an alternating current excitation signal amplitude value was ±5 mV.

[Table 3]

	Average weight loss corrosion rate at 168 h in periodic infiltration corrosion test (g/(m^2·h))	Average weight loss corrosion rate at 168 h in salt mist test (g/(m^2·h))	Chloride ion concentration ≥3 mol/L		
			Self-corrosion potential (V)	Polarization resistance (kΩ/cm^2)	Self-corrosion current density (μA/cm^2)
Example 1	0.100	0.033	-0.100	2977	0.128
Example 2	0.095	0.033	-0.109	2954	0.127
Example 3	0.095	0.030	-0.111	2876	0.127
Example 4	0.090	0.029	-0.116	2862	0.126
Example 5	0.090	0.028	-0.119	2832	0.125
Example 6	0.085	0.027	-0.124	2829	0.124
Example 7	0.085	0.027	-0.125	2814	0.123
Example 8	0.085	0.026	-0.127	2788	0.123
Example 9	0.080	0.025	-0.128	2764	0.123
Example 10	0.075	0.024	-0.137	2763	0.122
Example 11	0.075	0.023	-0.139	2671	0.122

(continued)

	Average weight loss corrosion rate at 168 h in periodic infiltration corrosion test (g/(m^2·h))	Average weight loss corrosion rate at 168 h in salt mist test (g/(m^2·h))	Chloride ion concentration ≥3 mol/L		
			Self-corrosion potential (V)	Polarization resistance (kΩ/cm^2)	Self-corrosion current density (μA/cm^2)
Example 12	0.075	0.020	-0.139	2660	0.120
Example 13	0.070	0.020	-0.143	2605	0.120
Example 14	0.065	0.019	-0.145	2565	0.119
Example 15	0.060	0.018	-0.150	2546	0.119
Example 16	0.055	0.018	-0.150	2534	0.119
Comparative example 1	4.512	1.690	-0.552	0	9.440
Comparative example 2	4.730	1.700	-0.641	0	8.850
Comparative example 3	4.654	1.790	-0.855	0	8.850
Comparative example 4	4.689	1.620	-0.757	0	8.420

[0113] From Table 3, it can be seen that Examples 1-16 were much more superior to Comparative examples 1-4 in an aspect of the corrosion-resistant performance. In the periodic infiltration corrosion test, the average weight loss corrosion rate of the steel bar was 0.05-0.1 g/(m^2·h), in the salt mist corrosion test, the average weight loss corrosion rate of the steel bar was 0.01-0.04 g/(m^2·h), and the anti-corrosion performance was improved by more than 45 times through being compared with that of ordinary HRB400. In the electrochemical corrosion test, in simulated concrete pore fluid with the chloride ion concentration greater than or equal to 3 mol/L, the self-corrosion potential of the steel bar was -0.1 V to -0.15 V, the positive shift amplitude relative to the ordinary HRB400 exceeded 0.4 V, a polarization resistance of the steel bar was 2500-3000 kΩ/cm^2, and was much greater than that of ordinary HRB400, and a self-corrosion current density of the steel bar was less than or equal to 0.13 μA/cm^2, and equaled to 1/65 or even less of that of ordinary HRB400.

[0114] In addition, for the steel bar according to Examples 1-16, inclusion detection and micro-structure detection were performed through sampling. An A-type inclusion, B-type inclusion, C-type inclusion and D-type inclusion at the standard of GB/T10561 were all less than or equal to 1.0 level. The micro-structure was ferrite and bainite, the ferrite accounted for 28%-40%, and the bainite accounted for 60%-72%.

[0115] Additionally, for the steel bar according to Examples 1-16, sampling was respectively performed, and a welding test was respectively performed by electric slag pressure welding. A tensile test was respectively performed on a welded sample according to a room temperature test method standard of part 1 of a metal material tensile test of GBT228.1-2010. A breaking point of the welded sample in the tensile test was formed in a base material position instead of a welding point position. Therefore, the obtained steel bar had excellent welding performance.

Claims

1. A 400 MPa corrosion-resistant steel bar, comprising the following chemical ingredients in percentage by mass: 9.5-10.4% of Cr, 1.0-1.2% of Mo, 0.3-0.6% of Mn, 0.01-1.00% of Ni, 0.01-0.5% of Cu, at most 0.014% of C, at most 0.004% of N, 0.01-0.05% of Nb, 0.2-0.6% of Si, at most 0.004% of S, at most 0.003% of O, at most 0.01% of As, 0.01-0.03% of P, and the balance of Fe and unavoidable impurities, wherein Cr+Mo+0.5Mn+0.35Ni+0.25Cu is 11.1-12.2%, and C+N+0.3Si+Mn+1.8Nb is 0.4-0.8%.

2. The 400 MPa corrosion-resistant steel bar according to claim 1, further comprising the following chemical ingredients in percentage by mass: any one or more of 0.1-0.15% of V, 0.01-0.05% of Ti, 0.01-0.03% of Al and 0.0005-0.0020% of B.

3. The 400 MPa corrosion-resistant steel bar according to claim 1, wherein a micro-structure of the steel bar is ferrite and bainite, and the ferrite accounts for 28%-40%.

4. The 400 MPa corrosion-resistant steel bar according to claim 1, wherein an A-type inclusion, B-type inclusion, C-type inclusion and D-type inclusion of the steel bar at the standard of GB/T10561 are all less than or equal to 1.0 level.

5. The 400 MPa corrosion-resistant steel bar according to claim 1, wherein a yield strength of the steel bar is greater than or equal to 420 MPa, a tensile strength is greater than or equal to 540 MPa, a percentage elongation after fracture is greater than or equal to 18%, and a maximum force total elongation percentage is greater than or equal to 7.5%.

6. The 400 MPa corrosion-resistant steel bar according to claim 1, wherein a nominal diameter of the steel bar is 6-32 mm.

7. The 400 MPa corrosion-resistant steel bar according to claim 6, wherein when the nominal diameter of the steel bar is 6-10 mm, the steel bar is made into a coiled steel bar; and when the nominal diameter of the steel bar is 12-32 mm, the steel bar is made into a straight steel bar.

8. The 400 MPa corrosion-resistant steel bar according to claim 1, wherein in a periodic infiltration corrosion test, an average weight loss corrosion rate of the steel bar is 0.05-0.1 g/(m^2·h); in a salt mist corrosion test, an average weight loss corrosion rate of the steel bar is 0.01-0.04 g/(m^2·h);
and in simulated concrete pore fluid with the chloride ion concentration greater than or equal to 3 mol/L, a self-corrosion potential of the steel bar is -0.1 V to -0.15 V, a polarization resistance is 2500-3000 kΩ/cm^2, and a self-corrosion current density is less than or equal to 0.13 μA/cm^2.

9. The 400 MPa corrosion-resistant steel bar according to claim 1, wherein the steel bar is able to be prepared by a process route I and a process route II,

wherein the process route I comprises a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an AOD furnace refining working procedure, an LF furnace refining working procedure, a square billet continuous casting working procedure, a hot continuous rolling working procedure and a temperature-controlled cooling working procedure which are performed in sequence; and
the process route II comprises a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an LF furnace refining working procedure, an RH furnace refining working procedure, a square billet continuous casting working procedure, a hot continuous rolling working procedure and a temperature-controlled cooling working procedure which are performed in sequence.

10. The 400 MPa corrosion-resistant steel bar according to claim 9, wherein in the process route I:

a tapping temperature of the converter smelting working procedure is 1600-1660°C;
in the AOD furnace refining working procedure, high-carbon ferro-chrome alloy and ferro-molybdenum alloy are added into molten steel to realize preliminary alloying on the molten steel, slagging-off is performed after reduction, then, manganese alloy is added, before tapping, a steel ladle for tapping is purged by argon gas for 5 min or a longer time, 20 kg of aluminum ingots are added into the molten steel in the tapping process, a tapping temperature is 1630-1670°C, and a tapping C content is less than or equal to 0.010%;
in the LF furnace refining working procedure, after the molten steel reaches the steel ladle of an LF furnace, slag regulation is performed according to a scheme of adding 13-15 kg of lime and 4.0-6.5 kg of fluorite into per ton of molten steel, a white slag maintaining time is greater than or equal to 8 min, a soft stirring time is 8-15 min, and a tapping temperature is 1600-1620°C; and
in the square billet continuous casting working procedure, carbon-free protection slag or ultra-low-carbon protection slag is used, a continuous casting temperature is 1520-1560°C, and a drawing speed in the continuous casting process is 1.2-1.6 m/min.

11. The 400 MPa corrosion-resistant steel bar according to claim 9, wherein in the process route II:

in the converter smelting working procedure, micro-carbon ferro-chrome alloy is added into molten steel in the tapping process to realize preliminary alloying on the molten steel, and a tapping temperature is 1700-1750°C;
in the LF furnace refining working procedure, a steel ladle in an LF furnace is subjected to whole-process bottom

blowing at an argon gas flow rate of 80-160 L/min, and a tapping temperature is 1560-1600°C;
in the RH furnace refining working procedure, after vacuum pumping on an RH furnace for 3 min, oxygen is started to be blown into the RH furnace, a total oxygen blowing amount is 500-700 Nm^3, then, micro-carbon ferro-chrome alloy is added into molten steel to realize alloying on the molten steel, clean circulation treatment is performed for 5 min or a longer time when a vacuum degree is less than 2 mbar, a tapping temperature is 1560-1600°C, and a tapping C content is less than or equal to 0.015%; and
in the square billet continuous casting working procedure, carbon-free protection slag or ultra-low-carbon protection slag is used, a continuous casting temperature is 1520-1560°C, and a drawing speed in the continuous casting process is 2.2-2.6 m/min.

12. The 400 MPa corrosion-resistant steel bar according to claim 9, wherein according to the process route I and the process route II:

in the hot continuous rolling working procedure, continuous-casting billets are heated in heating furnaces, a heating temperature is 1100-1200°C, an in-furnace time is 60-120 min, then, the billets are rolled into straight thread steel bars with a diameter of 12-32 mm, an initial rolling temperature is 1000-1100°C, and a finish rolling temperature is 850-950°C; and
in the temperature-controlled cooling working procedure, the rolled straight thread steel bars are naturally cooled on a cooling bed, and a temperature on the cooling bed is 860-920°C.

13. The 400 MPa corrosion-resistant steel bar according to claim 9, wherein according to the process route I and the process route II:
in the hot continuous rolling working procedure, continuous-casting billets are heated in heating furnaces, a heating temperature is 1080-1130°C, an in-furnace time is 60-120 min, then, the billets are rolled into coiled thread steel bars with a diameter of 6-10 mm, an initial rolling temperature is 980-1030°C, a finish rolling temperature is 850-950°C, and a spinning temperature is 830-920°C.

14. The 400 MPa corrosion-resistant steel bar according to claim 9, wherein both the process route I and the process route II comprise an on-line acid pickling working procedure and a packing working procedure which are performed in sequence after the temperature-controlled cooling working procedure; and
in the on-line acid pickling working procedure, the steel bars sequentially pass through an acid pickling tank, a passivation tank and a drying device, and gas jet holes of the acid pickling tank are distributed around a center line of the acid pickling tank.

15. The 400 MPa corrosion-resistant steel bar according to claim 1, wherein when the two steel bars are connected into a welded sample through electric slag pressure welding, a breaking point of the obtained welded sample in a tensile test is formed in a base material position of the two steel bars.

16. A production method of a 400 MPa corrosion-resistant steel bar, comprising the following steps:

(1) steel making:
sequentially using a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an AOD furnace refining working procedure and an LF furnace refining working procedure for molten steel melting, or sequentially using a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an LF furnace refining working procedure and an RH furnace refining working procedure for molten steel melting, and making the molten steel into steel billets through continuous casting, wherein the steel billets comprise the following chemical ingredients in percentage by mass: 9.5-10.4% of Cr, 1.0-1.2% of Mo, 0.3-0.6% of Mn, 0.01-1.00% of Ni, 0.01-0.5% of Cu, at most 0.014% of C, at most 0.004% of N, 0.01-0.05% of Nb, 0.2-0.6% of Si, at most 0.004% of S, at most 0.003% of O, at most 0.01% of As, 0.01-0.03% of P, and the balance of Fe and unavoidable impurities, wherein Cr+Mo+0.5Mn+0.35Ni+0.25Cu is 11.1-12.2%, and C+N+0.3Si+Mn+1.8Nb is 0.4-0.8%; and
(2) controlled rolling and controlled cooling:

heating the steel billets obtained in Step (1) in a heating furnace at a heating temperature of 1100-1200°C for an in-furnace time of 60-120 min, then, rolling the steel billets into straight thread steel bars with a diameter of 12-32 mm at an initial rolling temperature of 1000-1100°C and a finish rolling temperature of 850-950°C; then, naturally cooling the rolled straight thread steel bars on a cooling bed at a temperature on the cooling bed of 860-920°C;

or heating the steel billets obtained in Step (1) in a heating furnace at a heating temperature of 1080-1130°C for an in-furnace time of 60-120 min, then, rolling the steel billets into coiled thread steel bars with a diameter of 6-10 mm at an initial rolling temperature of 980-1030°C, a finish rolling temperature of 850-950°C, and a spinning temperature of 830-920°C, then, cooling the rolled coiled thread steel bars in a Stelmor cooling manner while all fans under a roller bed are turned off.

17. The production method of a 400 MPa corrosion-resistant steel bar according to claim 16, wherein in Step (1), the steel billets further comprise the following chemical ingredients in percentage by mass: any one or more of 0.1-0.15% of V, 0.01-0.05% of Ti, 0.01-0.03% of Al and 0.0005-0.0020% of B.

18. The production method of a 400 MPa corrosion-resistant steel bar according to claim 16, wherein in Step (1), if a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an AOD furnace refining working procedure and an LF furnace refining working procedure are sequentially used for molten steel melting, a tapping temperature of the converter smelting working procedure is 1600-1660°C; in the AOD furnace refining working procedure, high-carbon ferro-chrome alloy and ferro-molybdenum alloy are added into molten steel to realize preliminary alloying on the molten steel, slagging-off is performed after reduction, then, manganese alloy is added, before tapping, a steel ladle for tapping is purged by argon gas for 5 min or a longer time, 20 kg of aluminum ingots are added into the molten steel in the tapping process, a tapping temperature is 1630-1670°C, and a tapping C content is less than or equal to 0.01%; in the LF furnace refining working procedure, after the molten steel reaches the steel ladle of an LF furnace, slag regulation is performed according to a scheme of adding 13-15 kg of lime and 4.0-6.5 kg of fluorite into per ton of molten steel, a white slag maintaining time is greater than or equal to 8 min, a soft stirring time is 8-15 min, and a tapping temperature is 1600-1620°C; and in the square billet continuous casting working procedure, carbon-free protection slag or ultra-low-carbon protection slag is used, a continuous casting temperature is 1520-1560°C, and a drawing speed in the continuous casting process is 1.2-1.6 m/min; and
if a molten iron pre-desulfuration working procedure, a converter smelting working procedure, an LF furnace refining working procedure and an RH furnace refining working procedure are sequentially used for molten steel melting, in the converter smelting working procedure, micro-carbon ferro-chrome alloy is added into molten steel in the tapping process to realize preliminary alloying on the molten steel, and a tapping temperature is 1700-1750°C; in the LF furnace refining working procedure, a steel ladle in an LF furnace is subjected to whole-process bottom blowing at an argon gas flow rate of 80-160 L/min, and a tapping temperature is 1560-1600°C; in the RH furnace refining working procedure, after vacuum pumping on an RH furnace for 3 min, oxygen is started to be blown into the RH furnace, a total oxygen blowing amount is 500-700 Nm^3, then, micro-carbon ferro-chrome alloy is added into molten steel to realize alloying on the molten steel, clean circulation treatment is performed for 5 min or a longer time when a vacuum degree is less than 2 mbar, a tapping temperature is 1560-1600°C, and a tapping C content is less than or equal to 0.015%; and in the square billet continuous casting working procedure, carbon-free protection slag or ultra-low-carbon protection slag is used, a continuous casting temperature is 1520-1560°C, and a drawing speed in the continuous casting process is 2.2-2.6 m/min.

19. The production method of a 400 MPa corrosion-resistant steel bar according to claim 16, further comprising following steps:
(3) on-line acid pickling:
sequentially passing the steel bars obtained in Step (2) through an acid pickling tank, a passivation tank and a drying device for on-line acid pickling, wherein gas jet holes of the acid pickling tank are distributed around a center line of the acid pickling tank; and packing the steel bars after the steel bars leave away from the drying device.

20. The production method of a 400 MPa corrosion-resistant steel bar according to claim 16, wherein when the two steel bars prepared by the production method are connected into a welded sample through electric slag pressure welding, a breaking point of the obtained welded sample in a tensile test is formed in a base material position of the two steel bars.

INTERNATIONAL SEARCH REPORT

International application No. **PCT/CN2021/086677**

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/44(2006.01)i; C22C 38/04(2006.01)i; C22C 38/42(2006.01)i; C22C 38/48(2006.01)i; C22C 38/02(2006.01)i; C22C 38/46(2006.01)i; C22C 38/50(2006.01)i; C22C 38/54(2006.01)i; C22C 38/06(2006.01)i; C21D 8/08(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; C21D

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)

CNABS, CNTXT, CNKI, EPODOC, DWPI, SIPOABS: 钢筋, 钒, 镍, 锰, 钼, 铬, V, Ni, Mn, Mo, Cr, vanadium, nickel, manganese, molybdenum, chrom

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
PX	CN 112375995 A (JIANGSU SHAGANG INSTITUTE OF RESEARCH OF IRON AND STEEL et al.) 19 February 2021 (2021-02-19) claims 1-20	1-20
Y	CN 103789677 A (JIANGSU INSTITUTE OF RESEARCH OF IRON AND STEEL, SHA-STEEL CO., LTD.) 14 May 2014 (2014-05-14) see claim 4, description paragraphs 0008-0025, 0030-0034, table 1 embodiment 5	1-20
Y	CN 109972035 A (JIANGSU SHAGANG INSTITUTE OF RESEARCH OF IRON AND STEEL et al.) 05 July 2019 (2019-07-05) description, paragraph [0022]	1-20
A	CN 103255349 A (JIANGSU INSTITUTE OF RESEARCH OF IRON AND STEEL, SHA-STEEL CO., LTD.) 21 August 2013 (2013-08-21) entire document	1-20
A	CN 103898408 A (JIANGSU INSTITUTE OF RESEARCH OF IRON AND STEEL, SHA-STEEL CO., LTD.) 02 July 2014 (2014-07-02) entire document	1-20
A	WO 2020058330 A1 (SMS GROUP GMBH) 26 March 2020 (2020-03-26) entire document	1-20

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

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- "O" document referring to an oral disclosure, use, exhibition or other means
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- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08 October 2021	**14 October 2021**
Name and mailing address of the ISA/CN **China National Intellectual Property Administration (ISA/CN)** **No. 6, Xitucheng Road, Jimenqiao, Haidian District, Beijing 100088, China** Facsimile No. **(86-10)62019451**	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2021/086677

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2021/086677

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				DE	602007000326	D1	22 January 2009
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				EP	1818422	B1	10 December 2008
				DK	1818422	T3	23 February 2009
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REFERENCES CITED IN THE DESCRIPTION

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