

CORROSION-RESISTANT ALLOY STEEL BAR AND PREPARATION METHOD THEREFOR

CROSS REFERENCE TO RELATED APPLICATIONS

The present application claims priority to Chinese Patent Application No. 202210708417.8, entitled “CORROSION-RESISTANT ALLOY STEEL BAR AND PREPARATION METHOD THEREFOR”, and filed to the China National Intellectual Property Administration on June 22, 2022, the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD

The present application relates to the technical field of steel bars, in particular to a corrosion-resistant alloy steel bar and a preparation method therefor.

BACKGROUND

Reinforced concrete structures are the most dominating building structures, and their insufficient durability has become an industry problem. Corrosion-resistant alloy steel bars have the appearance, mechanical properties, processing performance of ordinary steel bars and corrosion resistance. Corrosion-resistant alloy steel bars have become an important means to solve the problem of insufficient durability of reinforced concrete structures. However, there are still some problems that the use of existing corrosion-resistant alloy steel bars is difficult to fully promote.

For example, patent CN112375995A discloses a 400MPa-level corrosion-resistant steel bar and preparation method therefor. The components of the 400MPa-level corrosion-resistant steel bar comprise in mass percentage: 9.5% to 10.4% of Cr, 1.0% to 1.2% of Mo, 0.3% to 0.6% of Mn, 0.01% to 1% of Ni, 0.01% to 0.5% of Cu, 0-0.014% of C, 0-0.004% of N, 0.01% to 0.05% of Nb, 0.2% to 0.6% of Si, and the balance of Fe and inevitable impurities. The microstructure of the above-mentioned corrosion-resistant steel bar is bainite and ferrite, which belongs to ultralow-carbon high-alloy corrosion-resistant steel bars and has excellent mechanical properties and corrosion resistance.

However, the high content of Cr and Mo in the alloy elements of above corrosion-resistant steel bar results in high production costs thereof, which greatly limits the application of corrosion-resistant steel bars.

SUMMARY OF THE INVENTION

The technical problem to be solved by the present application is to overcome the defects in the prior art that the alloy elements of corrosion-resistant steel bars have high Cr and Mo contents, which results in high production costs thereof and greatly limits the application of corrosion-resistant steel bars.

To this end, the present application provides a corrosion-resistant alloy steel bar, wherein, in percentage by weight, the corrosion-resistant alloy steel bar comprises 0.05% to 0.25% of C, 1.05% to 2% of Si, 0.3% to 1.5% of Mn, 0.5% to 2.5% of Cr, 0.05% to 1% of Ni, 0.001% to 0.005% of O, 0.001% to 0.0035% of S, 0.005% to 0.1% of Ti, 0.005% to 0.1% of Al, 0.005% to 0.03% of V, 0.005% to 0.03% of Nb, and the balance of Fe and inevitable impurities;

wherein, the content of Si and Mn satisfies $2 \leq \text{Si/Mn} \leq 5$; the content of Si and Cr satisfies $0.75 \leq \text{Si/Cr} \leq 1.5$; and the content of Ti and Al satisfies $0.02\% \leq (\text{Ti} + \text{Al}) \leq 0.2\%$.

Optionally, the content of Si is in a range from 1.2% to 1.8%;

and/or, the content of Mn is in a range from 0.4% to 1%;

and/or, the content of Cr is in a range from 0.85% to 2%.

Optionally, the content of Si is in a range from 1.35% to 1.65%;

and/or, the content of Mn is in a range from 0.45% to 0.75%;

and/or, the content of Cr is in a range from 1.35% to 1.75%.

Optionally, the content of C is in a range from 0.05% to 0.15%.

Optionally, the content of C is in a range from 0.07% to 0.12%.

Optionally, the content of Ti is in a range from 0.01% to 0.075%;

and/or, the content of Al is in a range from 0.01% to 0.075%.

The present application further provides a method for preparing corrosion-resistant alloy steel bar above, wherein the method comprises the processes of smelting, refining, continuous casting, rolling and cooling in sequence.

Optionally, raw materials for preparing the corrosion-resistant alloy steel bar comprise ferro-silicon alloy and silicon-manganese alloy, and a mass ratio of ferro-silicon alloy to silicon-manganese alloy is in a range from 2:1 to 5:1.

Optionally, during the process of continuous casting, a casting speed is in a range from 2.5 m/min to 3.5m/min;

and/or, during the process of cooling, a temperature of steel bar when moved onto a cooling bed is in

a range from 820°C to 1000°C;

and/or, the process of rolling comprises the steps of heating the continuous casting steel billet, rough rolling and finish rolling.

Optionally, a temperature for heating the continuous casting steel billet is in a range from 1,150°C to 1,250°C; a temperature for the rough rolling is in a range from 1,000°C to 1,120°C; and a temperature for the finish rolling is 1000°C or higher.

The technical solution of the present application has the following advantages.

1. The present application provides a corrosion-resistant alloy steel bar. Through the related design of Si, Mn, Cr, Al, and Ti in the formula of the present application, Si, Ti, Al, Mn and other elements are used to compensate for the decrease of corrosion resistance caused by the reduced Cr content. Therefore, under the conditions that Mo element needs not to be added into the formula and the content of Cr element is greatly reduced, corrosion-resistant alloy steel bars with excellent mechanical properties and corrosion resistance can be obtained, which greatly reduces the production cost of corrosion-resistant steel alloy bars.

2. The corrosion-resistant alloy steel bar provided by the present application, based on the chemical composition design of the present application, can not only achieve the excellent corrosion resistance of the corrosion-resistant alloy steel bar, but also make the corrosion-resistant alloy steel bar have excellent mechanical properties and lower production costs, which is suitable for actual production and processing.

3. The corrosion-resistant alloy steel bar provided by the present application, on the premise of the chemical composition design scheme of the present application, combined with the smelting technology as well as the processes of controlling rolling and cooling in the preparation method, ensures the strengthening effect of alloy elements as well as the acquisition of ferrite and pearlite duplex structure, which ensures the corrosion resistance and mechanical properties of the corrosion-resistant alloy steel bar, and reduces production difficulty and production cost at the same time.

DETAILED DESCRIPTION

The following examples are provided for a better understanding of the present application, are not limited to the best embodiments, and do not constitute a limitation on the content and scope of protection of the present application. Any product identical or similar to the present application, derived by anyone under the inspiration of the present application or by combining the present application with other

features of the prior art, falls within the scope of protection of the present application.

Where specific experimental steps or conditions are not indicated in the examples, the operations or conditions of conventional experimental steps described in the literatures in the present art can be followed. The reagents or instruments used without the manufacturer indicated are conventional reagents and products that are commercially available.

The particle diameter of the ferro-silicon alloy in the present application is in a range from 10mm to 30mm, and its main components in weight percentage are: 75% of Si, 0.002% of S, 0.01% of C, 0.1% of Al, 0.01% of Ti, 0.02% of P, the balance of iron and impurities, purchased from Qinghai Baitong High Purity Materials Co., Ltd.

The particle diameter of the silicon-manganese alloy in the present application is in a range from 10mm to 30mm, and its main components in weight percentage are: 83% of Mn, 1.94% of Si, 0.65% of C, 0.15% of P, 0.005% of S, and the balance of iron and impurities, purchased from Ningxia Yitong Industrial Co., Ltd.

The particle diameter of the ferro-chromium alloy in the present application is in a range from 30mm to 50mm, and its main components in weight percentage are: 60% of Cr, 0.87% of Si, 0.14% of C, 0.002% of S, 0.034% of P, and the balance of iron and impurities, purchased from Tianjin Haoyuan Metal Materials Co., Ltd.

The particle diameter of the ferro-titanium alloy in the present application is in a range from 10mm to 30mm, and its main components in weight percentage are: 1.85% of Si, 0.014% of S, 0.04% of C, 1.35% of Al, 32.94% of Ti, 0.042 % of P, 1.57% of Mn, and the balance of iron and impurities, purchased from Jinzhou Haixin Metal Materials Co., Ltd.

The particle diameter of the ferro-niobium alloy in the present application is in a range from 5mm to 30mm, and its main components in weight percentage are: 65.92% of Nb, 1.97% of Si, 0.12% of C, 0.94% of Al, 0.018% of S, 0.258 % of P, and the balance of iron and impurities, purchased from Beijing Hi-Tech New Materials Technology Co., Ltd.

The particle diameter of the vanadium-nitrogen alloy in the present application is in a range from 5mm to 10mm, and its main components in weight percentage are: 77.69% of V, 0.075% of S, 5.53% of C, 14.1% of N, 0.045% of P, and the balance of iron and impurities, purchased from Jiangsu Runfeng Synthetic Technology Co., Ltd.

In the present application, nickel is added in the manner of nickel plate which has a nickel content of

99.9% and the balance of iron and impurity elements, and was purchased from Jiangsu Guoyan Special Steel Co., Ltd.

In the present application, aluminum is added in the manner of aluminum particles, which has an aluminum content of 99.5% and the balance of iron and impurity elements, and was purchased from Xuchang Shengtong Metal Materials Co., Ltd.

Example 1

The present application provides a corrosion-resistant alloy steel bar, in percentage by weight, comprising: 0.07% of C, 1.35% of Si, 0.45% of Mn, 1.35% of Cr, 0.05% of Ni, 0.001% of O, 0.001% of S, 0.01% of Ti, 0.01% of Al, 0.005% of V, 0.005% of Nb, and the balance of Fe and inevitable impurities;

wherein the content of Si and Mn satisfies $\text{Si/Mn}=3$; the content of Si and Cr satisfies $\text{Si/Cr}=1$; and the content of Ti and Al satisfies $\text{Ti+Al}=0.02\%$.

The method for preparing the corrosion-resistant alloy steel bar above comprises the following steps:

the process of smelting: ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy, ferro-silicon alloy, silicon-manganese alloy, nickel plate and aluminum particles were smelted at $1,610^{\circ}\text{C}$ to obtain molten steel; wherein, the mass ratio of ferro-silicon alloy to silicon-manganese alloy is 3.3:1; the mass ratio of ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy and silicon-manganese alloy is 3.3:0.05:0.1:0.05:1; the addition amount of nickel plate is 60kg; the addition amount of aluminum particles is 25kg; and the addition amount of silicon-manganese alloy is 750kg;

the process of refining: argon gas was introduced into the molten steel and the materials were continuously refined at $1,550^{\circ}\text{C}$ for 40 minutes;

the process of continuous casting: a continuous casting machine was used to make a continuous casting steel billet from the refined molten steel; the casting speed was set to 3m/min during continuous casting, and the cross-sectional size of the obtained continuous casting steel billet is 140mm^2 ;

the process of rolling: the continuous casting steel billet obtained in the process of continuous casting was heated to $1,190^{\circ}\text{C}$ for a time period of 100min, then the temperature for the rough rolling was set to $1,035^{\circ}\text{C}$, the temperature for the finish rolling was set to $1,000^{\circ}\text{C}$, and the materials were rolled to obtain steel bars with a diameter of 14mm; and

the process of cooling: after the steel bars obtained in the process of rolling were cooled to 920°C , they were firstly moved onto the cooling bed for cooling and then air-cooled; and the conveying speed of

the cooling bed is 2m/min.

Example 2

The present application provides a corrosion-resistant alloy steel bar, in percentage by weight, comprising: 0.1% of C, 1.5% of Si, 0.55% of Mn, 1.5% of Cr, 0.5% of Ni, 0.003% of O, 0.0025% of S, 0.05% of Ti, 0.05% of Al, 0.015% of V, 0.015% of Nb, and the balance of Fe and inevitable impurities;

wherein the content of Si and Mn satisfies $\text{Si/Mn}=2.7$; the content of Si and Cr satisfies $\text{Si/Cr}=1$; and the content of Ti and Al satisfies $\text{Ti+Al}=0.1\%$.

The method for preparing the corrosion-resistant alloy steel bar above comprises the following steps:

the process of smelting: ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy, ferro-silicon alloy, silicon-manganese alloy, nickel plate and aluminum particles were smelted at $1,630^{\circ}\text{C}$ to obtain molten steel; wherein, the mass ratio of ferro-silicon alloy to silicon-manganese alloy is 3.1:1; the mass ratio of ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy and silicon-manganese alloy is 3.1:0.15:0.5:0.15:1; the addition amount of nickel plate is 600kg; the addition amount of aluminum particles is 130kg; and the addition amount of silicon-manganese alloy is 920kg;

the process of refining: argon gas was introduced into the molten steel and the materials were continuously refined at $1,555^{\circ}\text{C}$ for 40 minutes;

the process of continuous casting: a continuous casting machine was used to make a continuous casting steel billet from the refined molten steel; the casting speed was set to 3m/min during continuous casting, and the cross-sectional size of the obtained continuous casting steel billet is 140mm^2 ;

the process of rolling: the continuous casting steel billet obtained in the process of continuous casting was heated to $1,210^{\circ}\text{C}$ for a time period of 110min, then the temperature for the rough rolling was set to $1,025^{\circ}\text{C}$, the temperature for the finish rolling was set to $1,010^{\circ}\text{C}$, and the materials were rolled to obtain steel bars with a diameter of 25mm; and

the process of cooling: after the steel bars obtained in the process of rolling were cooled to 930°C , they were firstly moved onto the cooling bed for cooling and then air-cooled; and the conveying speed of the cooling bed is 1.5m/min.

Example 3

The present application provides a corrosion-resistant alloy steel bar, in percentage by weight, comprising: 0.12% of C, 1.65% of Si, 0.75% of Mn, 1.75% of Cr, 1% of Ni, 0.005% of O, 0.0035% of S,

0.075% of Ti, 0.075% of Al, 0.03% of V, 0.03% of Nb, and the balance of Fe and inevitable impurities;

wherein, the content of Si and Mn satisfies $\text{Si/Mn}=2.2$; the content of Si and Cr satisfies $\text{Si/Cr}=0.94$; and the content of Ti and Al satisfies $\text{Ti+Al}=0.15\%$.

The method for preparing the corrosion-resistant alloy steel bar above comprises the following steps:

the process of smelting: ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy, ferro-silicon alloy, silicon-manganese alloy, nickel plate and aluminum particles were smelted at $1,635^{\circ}\text{C}$ to obtain molten steel; wherein, the mass ratio of ferro-silicon alloy to silicon-manganese alloy is 2.5:1; the mass ratio of ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy and silicon-manganese alloy is 2.7:0.3:0.8:0.3:1; the addition amount of nickel plate is 1,200kg; the addition amount of aluminum particles is 250kg; and the addition amount of silicon-manganese alloy is 1,250kg;

the process of refining: argon gas was introduced into the molten steel and the materials were continuously refined at $1,515^{\circ}\text{C}$ for 50 minutes;

the process of continuous casting: a continuous casting machine was used to make a continuous casting steel billet from the refined molten steel; the casting speed was set to 2.6m/min during continuous casting, and the cross-sectional size of the obtained continuous casting steel billet is 140mm^2 ;

the process of rolling: the continuous casting steel billet obtained in the process of continuous casting was heated to $1,210^{\circ}\text{C}$ for a time period of 110min, then the temperature for the rough rolling was set to $1,025^{\circ}\text{C}$, the temperature for the finish rolling was set to $1,010^{\circ}\text{C}$, and the materials were rolled to obtain steel bars with a diameter of 32mm; and

the process of cooling: after the steel bars obtained in the process of rolling were cooled to 880°C , they were firstly moved onto the cooling bed for cooling and then air-cooled; and the conveying speed of the cooling bed is 1.1m/min.

Example 4

The present application provides a corrosion-resistant alloy steel bar, in percentage by weight, comprising: 0.05% of C, 1.2% of Si, 0.4% of Mn, 0.85% of Cr, 0.05% of Ni, 0.001% of O, 0.001% of S, 0.005% of Ti, 0.025% of Al, 0.005% of V, 0.005% of Nb, and the balance of Fe and inevitable impurities;

wherein, the content of Si and Mn satisfies $\text{Si/Mn}=3$; the content of Si and Cr satisfies $\text{Si/Cr}=1.41$; and the content of Ti and Al satisfies $\text{Ti+Al}=0.03\%$.

The method for preparing the corrosion-resistant alloy steel bar above comprises the following steps:

the process of smelting: ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy, ferro-silicon alloy, silicon-manganese alloy, nickel plate and aluminum particles were smelted at 1,600°C to obtain molten steel; wherein, the mass ratio of ferro-silicon alloy to silicon-manganese alloy is 3.5:1; the mass ratio of ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy and silicon-manganese alloy is 2.5:0.05:0.05:0.05:1; the addition amount of nickel plate is 60kg; the addition amount of aluminum particles is 70kg; and the addition amount of silicon-manganese alloy is 670kg;

the process of refining: argon gas was introduced into the molten steel and the materials were continuously refined at 1,540°C for 30 minutes;

the process of continuous casting: a continuous casting machine was used to make a continuous casting steel billet from the refined molten steel; the casting speed was set to 3m/min during continuous casting, and the cross-sectional size of the obtained continuous casting steel billet is 140mm²;

the process of rolling: the continuous casting steel billet obtained in the process of continuous casting was heated to 1,230°C for a time period of 120min, then the temperature for the rough rolling was set to 1,070°C, the temperature for the finish rolling was set to 1,050°C, and the materials were rolled to obtain steel bars with a diameter of 28mm; and

the process of cooling: after the steel bars obtained in the process of rolling were cooled to 920°C, they were firstly moved onto the cooling bed for cooling and then air-cooled; and the conveying speed of the cooling bed is 1.2m/min.

Example 5

The present application provides a corrosion-resistant alloy steel bar, in percentage by weight, comprising: 0.15% of C, 1.8% of Si, 0.9% of Mn, 2% of Cr, 1% of Ni, 0.005% of O, 0.0035% of S, 0.1% of Ti, 0.1% of Al, 0.03% of V, 0.03% of Nb; and the balance of Fe and inevitable impurities;

wherein, the content of Si and Mn satisfies $Si/Mn=2$; the content of Si and Cr satisfies $Si/Cr=0.9$; and the content of Ti and Al satisfies $Ti+Al=0.2\%$.

The method for preparing the corrosion-resistant alloy steel bar above comprises the following steps:

the process of smelting: ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy, ferro-silicon alloy, silicon-manganese alloy, nickel plate and aluminum particles were smelted at 1,639°C to obtain molten steel; wherein, the mass ratio of ferro-silicon alloy to silicon-manganese alloy is 2:1; the mass ratio of ferro-chromium alloy, ferro-niobium alloy,

ferro-titanium alloy, vanadium-nitrogen alloy and silicon-manganese alloy is 2.5:0.3:1.2:0.3:1; the addition amount of nickel plate is 1,200kg; the addition amount of aluminum particles is 30kg; and the addition amount of silicon-manganese alloy is 1,500kg;

the process of refining: argon gas was introduced into the molten steel and the materials were continuously refined at 1,560°C for 45 minutes;

the process of continuous casting: a continuous casting machine was used to make a continuous casting steel billet from the refined molten steel; the casting speed was set to 2.5m/min during continuous casting, and the cross-sectional size of the obtained continuous casting steel billet is 140mm²;

the process of rolling: the continuous casting steel billet obtained in the process of continuous casting was heated to 1,150°C for a time period of 90min, then the temperature for the rough rolling was set to 1,000°C, the temperature for the finish rolling was set to 1,000°C, and the materials were rolled to obtain steel bars with a diameter of 10mm; and

the process of cooling: after the steel bars obtained in the process of rolling were cooled to 820°C, they were firstly moved onto the cooling bed for cooling and then air-cooled; and the conveying speed of the cooling bed is 2.2m/min.

Example 6

The present application provides a corrosion-resistant alloy steel bar, in percentage by weight, comprising: 0.05% of C, 1.05% of Si, 0.3% of Mn, 0.8% of Cr, 0.05% of Ni, 0.001% of O, 0.001% of S, 0.025% of Ti, 0.005% of Al, 0.005% of V, 0.005% of Nb, and the balance of Fe and inevitable impurities;

wherein the content of Si and Mn satisfies $Si/Mn=3.5$; the content of Si and Cr satisfies $Si/Cr=1.31$; and the content of Ti and Al satisfies $Ti+Al=0.03\%$.

The method for preparing the corrosion-resistant alloy steel bar above comprises the following steps:

the process of smelting: ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy, ferro-silicon alloy, silicon-manganese alloy, nickel plate and aluminum particles were smelted at 1,650°C to obtain molten steel; wherein, the mass ratio of ferro-silicon alloy to silicon-manganese alloy is 3.8:1; the mass ratio of ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy and silicon-manganese alloy is 2.6:0.05:0.3:0.05:1; the addition amount of nickel plate is 60kg; the addition amount of aluminum particles is 20kg; and the addition amount of silicon-manganese alloy is 500kg;

the process of refining: argon gas was introduced into the molten steel and the materials were

continuously refined at 1,550°C for 35 minutes;

the process of continuous casting: a continuous casting machine was used to make a continuous casting steel billet from the refined molten steel; the casting speed was set to 2.5m/min during continuous casting, and the cross-sectional size of the obtained continuous casting steel billet is 140mm²;

the process of rolling: the continuous casting steel billet obtained in the process of continuous casting was heated to 1,180°C for a time period of 100min, then the temperature for the rough rolling was set to 1,020°C, the temperature for the finish rolling was set to 1,000°C, and the materials were rolled to obtain steel bars with a diameter of 18mm; and

the process of cooling: after the steel bars obtained in the process of rolling were cooled to 860°C, they were firstly moved onto the cooling bed for cooling and then air-cooled; and the conveying speed of the cooling bed is 1.4m/min.

Example 7

The present application provides a corrosion-resistant alloy steel bar, in percentage by weight, comprising: 0.25% of C, 2% of Si, 1% of Mn, 2.5% of Cr, 1% of Ni, 0.005% of O, 0.0035% of S, 0.1% of Ti, 0.1% of Al, 0.03% of V, 0.03% of Nb, and the balance of Fe and inevitable impurities;

wherein the content of Si and Mn satisfies Si/Mn=2; the content of Si and Cr satisfies Si/Cr=0.8; and the content of Ti and Al satisfies Ti+Al=0.2%.

The method for preparing the corrosion-resistant alloy steel bar above comprises the following steps:

the process of smelting: ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy, ferro-silicon alloy, silicon-manganese alloy, nickel plate and aluminum particles were smelted at 1,600°C to obtain molten steel; wherein, the mass ratio of ferro-silicon alloy to silicon-manganese alloy is 2.2:1; the mass ratio of ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy and silicon-manganese alloy is 3:0.3:1.1:0.3:1; the addition amount of nickel plate is 1,200kg; the addition amount of aluminum particles is 250kg; and the addition amount of silicon-manganese alloy is 1,665kg;

the process of refining: argon gas was introduced into the molten steel and the materials were continuously refined at 1,540°C for 40 minutes;

the process of continuous casting: a continuous casting machine was used to make a continuous casting steel billet from the refined molten steel; the casting speed was set to 2.7m/min during continuous casting, and the cross-sectional size of the obtained continuous casting steel billet is 140mm²;

the process of rolling: the continuous casting steel billet obtained in the process of continuous casting was heated to 1,250°C for a time period of 120min, then the temperature for the rough rolling was set to 1,120°C, the temperature for the finish rolling was set to 1,100°C, and the materials were rolled to obtain steel bars with a diameter of 22mm; and

the process of cooling: after the steel bars obtained in the process of rolling were cooled to 1,000°C, they were firstly moved onto the cooling bed for cooling and then air-cooled; and the conveying speed of the cooling bed is 1.45m/min.

Example 8

The present application provides a corrosion-resistant alloy steel bar, in percentage by weight, comprising: 0.1% of C, 1.05% of Si, 0.35% of Mn, 0.75% of Cr, 0.15% of Ni, 0.0025% of O, 0.0025% of S, 0.03% of Ti, 0.03% of Al, 0.01% of V, 0.01% of Nb, and the balance of Fe and inevitable impurities;

wherein the content of Si and Mn satisfies $\text{Si/Mn}=3$; the content of Si and Cr satisfies $\text{Si/Cr}=1.4$; and the content of Ti and Al satisfies $\text{Ti+Al}=0.06\%$.

The method for preparing the corrosion-resistant alloy steel bar above comprises the following steps:

the process of smelting: ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy, ferro-silicon alloy, silicon-manganese alloy, nickel plate and aluminum particles were smelted at 1,620°C to obtain molten steel; wherein, the mass ratio of ferro-silicon alloy to silicon-manganese alloy is 3.3:1; the mass ratio of ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy and silicon-manganese alloy is 2.1:0.1:0.3:0.1:1; the addition amount of nickel plate is 180kg; the addition amount of aluminum particles is 250kg; and the addition amount of silicon-manganese alloy is 585kg;

the process of refining: argon gas was introduced into the molten steel and the materials were continuously refined at 1,545°C for 40 minutes;

the process of continuous casting: a continuous casting machine was used to make a continuous casting steel billet from the refined molten steel; the casting speed was set to 3.5m/min during continuous casting, and the cross-sectional size of the obtained continuous casting steel billet is 140mm²;

the process of rolling: the continuous casting steel billet obtained in the process of continuous casting was heated to 1,200°C for a time period of 100min, then the temperature for the rough rolling was set to 1,020°C, the temperature for the finish rolling was set to 1,000°C, and the materials were rolled to obtain steel bars with a diameter of 16mm; and

the process of cooling: after the steel bars obtained in the process of rolling were cooled to 880°C, they were firstly moved onto the cooling bed for cooling and then air-cooled; and the conveying speed of the cooling bed is 1.6m/min.

Example 9

The present application provides a corrosion-resistant alloy steel bar, in percentage by weight, comprising: 0.25% of C, 1.5% of Si, 0.3% of Mn, 1% of Cr, 0.05% of Ni, 0.001% of O, 0.001% of S, 0.1% of Ti, 0.05% of Al, 0.005% of V, and 0.005% of Nb;

wherein the content of Si and Mn satisfies $\text{Si/Mn}=5$; the content of Si and Cr satisfies $\text{Si/Cr}=1.5$; and the content of Ti and Al satisfies $\text{Ti+Al}=0.15\%$.

The method for preparing the corrosion-resistant alloy steel bar above comprises the following steps:

the process of smelting: ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy, ferro-silicon alloy, silicon-manganese alloy, nickel plate and aluminum particles were smelted at 1,650°C to obtain molten steel; wherein, the mass ratio of ferro-silicon alloy to silicon-manganese alloy is 5:1; the mass ratio of ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy and silicon-manganese alloy is 3.3:0.05:1.1:0.05:1; the addition amount of nickel plate is 60kg; the addition amount of aluminum particles is 125kg; and the addition amount of silicon-manganese alloy is 500kg;

the process of refining: argon gas was introduced into the molten steel and the materials were continuously refined at 1,560°C for 60 minutes;

the process of continuous casting: a continuous casting machine was used to make a continuous casting steel billet from the refined molten steel; the casting speed was set to 3.1m/min during continuous casting, and the cross-sectional size of the obtained continuous casting steel billet is 140mm²;

the process of rolling: the continuous casting steel billet obtained in the process of continuous casting was heated to 1,230°C for a time period of 120min, then the temperature for the rough rolling was set to 1,060°C, the temperature for the finish rolling was set to 1,000°C, and the materials were rolled to obtain steel bars with a diameter of 22mm; and

the process of cooling: after the steel bars obtained in the process of rolling were cooled to 1,000°C, they were firstly moved onto the cooling bed for cooling and then air-cooled; and the conveying speed of the cooling bed is 1.45m/min.

Example 10

The present application provides a corrosion-resistant alloy steel bar, in percentage by weight, comprising: 0.05% of C, 1.86% of Si, 0.93% of Mn, 2.48% of Cr, 1% of Ni, 0.005% of O, 0.0035% of S, 0.005% of Ti, 0.015% of Al, 0.03% of V, and 0.03% of Nb;

wherein the content of Si and Mn satisfies $\text{Si/Mn}=2$; the content of Si and Cr satisfies $\text{Si/Cr}=0.75$; and the content of Ti and Al satisfies $\text{Ti+Al}=0.02\%$.

The method for preparing the corrosion-resistant alloy steel bar above comprises the following steps:

the process of smelting: ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy, ferro-silicon alloy, silicon-manganese alloy, nickel plate and aluminum particles were smelted at $1,600^{\circ}\text{C}$ to obtain molten steel; wherein, the mass ratio of ferro-silicon alloy to silicon-manganese alloy is 2.2:1; the mass ratio of ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy and silicon-manganese alloy is 3.0:0.3:0.2:0.3:1; the addition amount of nickel plate is 1,200kg; the addition amount of aluminum particles is 325kg; and the addition amount of silicon-manganese alloy is 1,550kg;

the process of refining: argon gas was introduced into the molten steel and the materials were continuously refined at $1,540^{\circ}\text{C}$ for 30 minutes;

the process of continuous casting: a continuous casting machine was used to make a continuous casting steel billet from the refined molten steel; the casting speed was set to 2.8m/min during continuous casting, and the cross-sectional size of the obtained continuous casting steel billet is 140mm^2 ;

the process of rolling: the continuous casting steel billet obtained in the process of continuous casting was heated to $1,180^{\circ}\text{C}$ for a time period of 90min, then the temperature for the rough rolling was set to $1,020^{\circ}\text{C}$, the temperature for the finish rolling was set to $1,000^{\circ}\text{C}$, and the materials were rolled to obtain steel bars with a diameter of 22mm; and

the process of cooling: after the steel bars obtained in the process of rolling were cooled to 950°C , they were firstly moved onto the cooling bed for cooling and then air-cooled; and the conveying speed of the cooling bed is 1.45m/min.

Comparative Example 1

The present application provides a corrosion-resistant alloy steel bar, in percentage by weight, comprising: 0.1% of C, 2.15% of Si, 0.3% of Mn, 1% of Cr, 0.05% of Ni, 0.001% of O, 0.0035% of S, 0.08% of Ti, 0.07% of Al, 0.005% of V, and 0.005% of Nb;

wherein the content of Si and Mn satisfies $\text{Si/Mn}=7.17$; the content of Si and Cr satisfies $\text{Si/Cr}=2.15$;

and the content of Ti and Al satisfies $Ti+Al=0.15\%$.

The only difference between the method for preparing the corrosion-resistant alloy steel bar above and Example 8 is that: in the process of smelting, the mass ratio of ferro-silicon alloy to silicon-manganese alloy is 6.5:1; the mass ratio of ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy and silicon-manganese alloy is 3.6:0.05:0.8:0.05:1; the addition amount of nickel plate is 60kg; the addition amount of aluminum particles is 180kg; and the addition amount of silicon-manganese alloy is 500kg.

Comparative Example 2

The present application provides a corrosion-resistant alloy steel bar, in percentage by weight, comprising: 0.1% of C, 1.5% of Si, 1.65% of Mn, 1% of Cr, 0.05% of Ni, 0.001% of O, 0.0035% of S, 0.08% of Ti, 0.07% of Al, 0.005% of V, and 0.005% of Nb;

wherein the content of Si and Mn satisfies $Si/Mn=0.91$; the content of Si and Cr satisfies $Si/Cr=1.5$; and the content of Ti and Al satisfies $Ti+Al=0.15\%$.

The only difference between the method for preparing the corrosion-resistant alloy steel bar above and Example 8 is that: in the process of smelting, the mass ratio of ferro-silicon alloy to silicon-manganese alloy is 0.8:1; the mass ratio of ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy and silicon-manganese alloy is 0.6:0.05:0.8:0.05:1; the addition amount of nickel plate is 60kg; the addition amount of aluminum particles is 180kg; and the addition amount of silicon-manganese alloy is 2,750kg.

Comparative Example 3

The present application provides a corrosion-resistant alloy steel bar, in percentage by weight, comprising: 0.1% of C, 1.5% of Si, 0.3% of Mn, 3% of Cr, 0.05% of Ni, 0.001% of O, 0.0035% of S, 0.08% of Ti, 0.07% of Al, 0.005% of V, and 0.005% of Nb;

wherein the content of Si and Mn satisfies $Si/Mn=5$; the content of Si and Cr satisfies $Si/Cr=0.5$; and the content of Ti and Al satisfies $Ti+Al=0.15\%$.

The only difference between the method for preparing the corrosion-resistant alloy steel bar above and Example 8 is that: in the process of smelting, the mass ratio of ferro-silicon alloy to silicon-manganese alloy is 4.5:1; the mass ratio of ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy and silicon-manganese alloy is 10:0.05:0.8:0.05:1; the addition amount of nickel plate is 60kg; the addition amount of aluminum particles is 180kg; and the

addition amount of silicon-manganese alloy is 500kg.

Comparative Example 4

The present application provides a corrosion-resistant alloy steel bar, in percentage by weight, comprising: 0.1% of C, 1.5% of Si, 0.3% of Mn, 1% of Cr, 0.05% of Ni, 0.001% of O, 0.0035% of S, 0.15% of Ti, 0.07% of Al, 0.005% of V, and 0.005% of Nb;

wherein the content of Si and Mn satisfies $\text{Si/Mn}=5$; the content of Si and Cr satisfies $\text{Si/Cr}=1.5$; and the content of Ti and Al satisfies $\text{Ti+Al}=0.22\%$.

The only difference between the method for preparing the corrosion-resistant alloy steel bar above and Example 8 is that: in the process of smelting, the mass ratio of ferro-silicon alloy to silicon-manganese alloy is 4.5:1; the mass ratio of ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy and silicon-manganese alloy is 3.3:0.05:1.55:0.05:1; the addition amount of nickel plate is 60kg; the addition amount of aluminum particles is 180kg; and the addition amount of silicon-manganese alloy is 500kg.

Comparative Example 5

The present application provides a corrosion-resistant alloy steel bar, in percentage by weight, comprising: 0.1% of C, 1.5% of Si, 0.3% of Mn, 1% of Cr, 0.05% of Ni, 0.001% of O, 0.0035% of S, 0.08% of Ti, 0.15% of Al, 0.005% of V, and 0.005% of Nb;

wherein the content of Si and Mn satisfies $\text{Si/Mn}=5$; the content of Si and Cr satisfies $\text{Si/Cr}=1.5$; and the content of Ti and Al satisfies $\text{Ti+Al}=0.22\%$.

The only difference between the method for preparing the corrosion-resistant alloy steel bar above and Example 8 is that: in the process of smelting, the mass ratio of ferro-silicon alloy to silicon-manganese alloy is 4.5:1; the mass ratio of ferro-chromium alloy, ferro-niobium alloy, ferro-titanium alloy, vanadium-nitrogen alloy and silicon-manganese alloy is 3.3:0.05:0.8:0.05:1; the addition amount of nickel plate is 60kg; the addition amount of aluminum particles is 380kg; and the addition amount of silicon-manganese alloy is 500kg.

Test Example 1

The mechanical properties of the corrosion-resistant alloy steel bars prepared in the Examples and Comparative Examples were tested in accordance with the national standard GB/T228.1-2010, "Metal Materials Tensile Test Part 1: Room Temperature Test Method", and the ratio of tensile strength and yield strength (i.e. tensile strength/yield strength) was calculated. The test results were shown in Table 1;

Table 1. Test results of Test Example 1

Test Example	Mechanical property				
	Yield strength /MPa	Tensile strength /MPa	Elongation after fracture /%	Total elongation at maximum force /%	Ratio of tensile strength and yield strength
Example 1	468	613	31.8	20.5	1.31
Example 2	481	640	30.6	19.5	1.33
Example 3	495	653	32.5	19.3	1.32
Example 4	468	604	25.3	15.4	1.29
Example 5	456	588	23.8	15.5	1.29
Example 6	430	542	21.7	11.3	1.26
Example 7	435	552	20.5	10.6	1.27
Example 8	435	548	20.5	12.5	1.26
Example 9	445	565	22.5	13.5	1.27
Example 10	448	569	23	13.1	1.27
Comparative Example 1	385	443	20.5	10.7	1.15
Comparative Example 2	370	437	28.5	14.1	1.18
Comparative Example 3	485	631	8.5	4.6	1.3
Comparative Example 4	456	575	14.5	6.9	1.26
Comparative Example 5	365	475	16.5	10.5	1.3

It can be seen from the data in Table 1 that, only when the proportions of various elements meet the conditions of the present application, can the yield strength ≥ 430 MPa, elongation after fracture $\geq 20.5\%$, ratio of tensile strength and yield strength ≥ 1.26 , and total elongation at maximum force $\geq 10.6\%$ be guaranteed at the same time, so that the excellent mechanical properties can be obtained under the cases that Mo element needs not to be added in the formula and the content of Cr element is greatly reduced.

Test Example 2

Zeiss optical microscope was used to observe the structural types of the corrosion-resistant alloy steel bars prepared in the Examples and Comparative Examples under a field of view of 200 times magnification, and the ferrite volume ratio therein was calculated. The test results were shown in Table 2.

Test Example 3

An electrochemical workstation equipped with a working electrode, a reference electrode, and a counter electrode system was used to test the critical chloride ion concentration value of the passive film rupture on the surface of the corrosion-resistant alloy steel bars prepared in the Examples and Comparative Examples, and the increase multiple of the critical chloride ion concentration value compared with that of the HRB400 type steel bar was calculated. The specific test method was: soaking

the test sample in a saturated sodium hydroxide solution for 48 hours, then loading it into the electrochemical workstation and serving as a working electrode; adding 0.01mol/L of sodium chloride solution into the electrochemical workstation solution every 24 hours, and testing the voltage/current-chloride ion concentration curve; when the current or voltage varies sharply, the corresponding chloride ion concentration value is the critical chloride ion concentration value. The calculation formula is: the increase multiple = critical chloride ion concentration value of corrosion-resistant alloy steel bar/critical chloride ion concentration value of HRB400 steel bar; and the test results were shown in Table 2. The composition ratio of the above HRB400 type steel bar was C: 0.24%, Si: 0.40%, Mn: 1.40%, V: 0.025%, P≤0.04 and S≤0.04%.

Test Example 4

The chlorine salt corrosion resistance of the corrosion-resistant alloy steel bars prepared in the Examples and Comparative Examples was tested respectively, and the increase multiple of the chlorine salt corrosion resistance compared thereof compared with that of the HRB400 type steel bar was calculated. The specific test method was: the 100mm long ends of the alloy corrosion-resistant steel bar of various Examples and Comparative Examples were cut off, and the test sample with a diameter of 8mm was obtained by turning it with a lathe; the test sample was put into the corrosion solution at a temperature of 35°C and a humidity of 80% for salt spray corrosion test. The corrosion solution for testing is a sodium chloride solution with a chloride salt concentration of 5wt%, and a pH value of 7.0, the testing time was 14 days, and the weight of the test samples before and after corrosion was measured using an electron microscope balance. The calculation formula is: increase multiple = weight variation value of corrosion-resistant alloy steel bar before and after corrosion/weight variation value of HRB400 type steel bar before and after corrosion. The test results were shown in Table 2. The composition ratio of the above HRB400 type steel bar was C: 0.24%, Si: 0.40%, Mn: 1.40%, V: 0.025%, P ≤ 0.04% and S ≤ 0.04%.

Table 2. Test results of Test Examples 2-4

Number	Microstructure type	Proportion of Ferrite /%	Increase multiples of critical chloride ion concentration value compared with HRB400	Increase multiples of chloride salt corrosion resistance compared with HRB400
Example 1	Ferrite+Pearlite	53	4.5	6.6
Example 2	Ferrite+Pearlite	55	4.2	7.5

Example 3	Ferrite+Pearlite	58	4.8	8.2
Example 4	Ferrite+Pearlite	63	3.3	3.7
Example 5	Ferrite+Pearlite	65	3	4.9
Example 6	Ferrite+Pearlite	73	2.4	2.7
Example 7	Ferrite+Pearlite	70	2.2	3.2
Example 8	Ferrite+Pearlite	68	2.1	3.3
Example 9	Ferrite+Pearlite	68	2.2	3.5
Example 10	Ferrite+Pearlite	65	2.7	3.4
Comparative Example 1	Ferrite+Pearlite	75	2.1	5
Comparative Example 2	Ferrite+Pearlite	80	1.1	3
Comparative Example 3	Ferrite+Pearlite+Bainite	33	2.5	4.5
Comparative Example 4	Ferrite+Pearlite	40	3	5.6
Comparative Example 5	Ferrite+Pearlite	85	3	7

It can be seen from the results in Table 2 above that in the corrosion-resistant alloy steel bars of the present application, the proportion of ferrite in the microstructure type reaches 53% to 73%. Compared with HRB400, the critical chloride ion concentration value was increased to 2.1 times and more, the chlorine salt corrosion resistance was improved to 2.7 times and more, and the comprehensive performance was significantly improved.

It can be concluded from the data in Table 1 and Table 2 that both the mechanical properties and corrosion resistance can be obtained under the composition ratio of the present application, and the comprehensive performance is remarkable. In addition, there is no Mo element in the composition ratio of the present application and the content of Cr element was greatly reduced, and the cost was significantly reduced.

Obviously, the above examples are merely examples made for clear description, rather limiting the embodiments. For those of ordinary skill in the art, other different forms of variations or modifications can also be made on the basis of the above-mentioned description. All embodiments are not necessary to be and cannot be exhaustively listed herein. In addition, obvious variations or modifications derived therefrom all fall within the scope of protection of the present application.

CLAIMS

1. A corrosion-resistant alloy steel bar, wherein, in percentage by weight, the corrosion-resistant alloy steel bar comprises 0.05% to 0.25% of C, 1.05% to 2% of Si, 0.3% to 1.5% of Mn, 0.5% to 2.5% of Cr, 0.05% to 1% of Ni, 0.001% to 0.005% of O, 0.001% to 0.0035% of S, 0.005% to 0.1% of Ti, 0.005% to 0.1% of Al, 0.005% to 0.03% of V, 0.005% to 0.03% of Nb, and the balance of Fe and inevitable impurities;

wherein, the content of Si and Mn satisfies $2 \leq \text{Si/Mn} \leq 5$; the content of Si and Cr satisfies $0.75 \leq \text{Si/Cr} \leq 1.5$; and the content of Ti and Al satisfies $0.02\% \leq (\text{Ti+Al}) \leq 0.2\%$.

2. The corrosion-resistant alloy steel bar of claim 1, wherein the content of Si is in a range from 1.2% to 1.8%;

and/or, the content of Mn is in a range from 0.4% to 1%;

and/or, the content of Cr is in a range from 0.85% to 2%.

3. The corrosion-resistant alloy steel bar of claim 2, wherein,

the content of Si is in a range from 1.35% to 1.65%;

and/or, the content of Mn is in a range from 0.45% to 0.75%;

and/or, the content of Cr is in a range from 1.35% to 1.75%.

4. The corrosion-resistant alloy steel bar of claim 1, wherein the content of C is in a range from 0.05% to 0.15%.

5. The corrosion-resistant alloy steel bar of claim 4, wherein the content of C is in a range from 0.07% to 0.12%.

6. The corrosion-resistant alloy steel bar of claim 1, wherein,

the content of Ti is in a range from 0.01% to 0.075%;

and/or, the content of Al is in a range from 0.01% to 0.075%.

7. A method for preparing the corrosion-resistant alloy steel bar of any one of claims 1 to 6, wherein

the method comprises the processes of smelting, refining, continuous casting, rolling, and cooling in sequence.

8. The method of claim 7, wherein raw materials for preparing the corrosion-resistant alloy steel bar comprise ferro-silicon alloy and silicon-manganese alloy, and a mass ratio of ferro-silicon alloy to silicon-manganese alloy is in a range from 2:1 to 5:1.

9. The method of claim 7, wherein,
during the process of continuous casting, a casting speed is in a range from 2.5 m/min to 3.5m/min;
and/or, during the process of cooling, a temperature of steel bar when moved onto a cooling bed is in a range from 820°C to 1,000°C;
and/or, the process of rolling comprises the steps of heating the continuous casting steel billet, rough rolling and finish rolling.

10. The method of claim 9, wherein a temperature for heating the continuous casting steel billet is in a range from 1,150°C to 1,250°C; a temperature for the rough rolling is in a range from 1,000°C to 1,120°C; and a temperature for the finish rolling is 1000°C or higher.