

## **S355G10 SUPER-THICK STEEL PLATE FOR OCEAN ENGINEERING AND MANUFACTURING METHOD**

### **Technical Field**

The present invention relates to the technical field of metallurgy, particularly to  
5 an S355G10 super-thick steel plate for ocean engineering and a manufacturing method  
thereof.

### **Background Art**

S355G10 steel is a steel grade in BS EN10225 standard “Weldable Structure  
10 Steels for Fixed Offshore Structures”, which specifies the chemical composition,  
mechanical properties, welding performance, etc. of offshore structural steel. At  
present, China has not formulated special standards for steel for ocean engineering. A  
low-carbon equivalent, microalloying, and a reasonable heat treatment process (such  
as normalizing) after controlled rolling are mostly adopted to develop S355G10+N  
15 and S355NL steel plates, which can meet the requirements for application in some  
offshore platforms and structural parts.

In terms of the development of steel for ocean engineering, the normalizing  
process has been used to produce S355G10+N products, and the TMCP process has  
been used to produce S355G10+M products. The main related invention patents are as  
20 follows:

CN104726769 discloses “Maximum-thickness S355G10+N steel plate for ocean  
platform and production method of steel plate”. The steelmaking adopts ingot casting,  
slabs are rolled subsequently and the steelmaking cost is high; the rolling of the super-  
thick steel plate requires heat treatment of normalization. The composition design  
25 includes 0.04% to 0.06% of V, resulting in a high alloy cost; in the normalization  
design, CEV is less than or equal to 0.43% and P<sub>cm</sub> is less than or equal to 0.22%,  
which are slightly high and are not favorable to the welding performance of the super-

thick steel plate.

CN108085604 discloses “Low-temperature toughness S355G10+M wide and heavy steel plate for oceanographic engineering and production method of low-temperature toughness S355G10+M wide and heavy steel plate”. The steel plate is produced according to the TMCP process, and the maximum thickness of the produced steel plate is only 100mm, which cannot fully meet the requirements of the super-thick steel plates of 100mm or more for the ocean engineering.

Therefore, there is an urgent need to develop a low-cost, large-thickness steel plate for ocean engineering.

### **Summary of the Invention**

In order to solve the foregoing technical problem, the present invention provides an S355G10 super-thick steel plate for ocean engineering, and the S355G10 super-thick steel plate is prepared from the following chemical components according to mass percent: 0.04% to 0.08% of C, 1.40% to 1.60% of Mn, 0.10% to 0.30% of Si, less than or equal to 0.013% of P, less than or equal to 0.003% of S, 0.015% to 0.030% of Nb, 0.010% to 0.020% of Ti, 0.020% to 0.055% of Al, 0.10% to 0.20% of Cr, 0.30% to 0.50% of Ni, less than or equal to 0.38% of CEV, less than or equal to 0.18% of P<sub>cm</sub> and the balance of Fe and impurities.

Technical effects: The present invention adopts low-carbon composition design, low-compression ratio rolling of a continuous casting slab, a tempering heat treatment process and the like, so that an S355G10 super-thick steel plate of 120 mm for the ocean engineering can be developed, and the alloy cost and the steelmaking cost are low.

The present invention further defines the following technical solution:

The foregoing S355G10 super-thick steel plate for ocean engineering is prepared from the following chemical components according to mass percent: 0.06% of C, 1.54% of Mn, 0.26% of Si, 0.010% of P, 0.002% of S, 0.027% of Nb, 0.013% of Ti, 0.035%

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of Al, 0.13% of Cr, 0.41% of Ni, 0.36% of CEV, 0.15% of P<sub>cm</sub> and the balance of Fe and impurities.

The foregoing S355G10 super-thick steel plate for ocean engineering is prepared from the following chemical components according to mass percent: 0.07% of C, 1.48% of Mn, 0.24% of Si, 0.011% of P, 0.002% of S, 0.025% of Nb, 0.015% of Ti, 0.033% of Al, 0.15% of Cr, 0.46% of Ni, 0.37% of CEV, 0.16% of P<sub>cm</sub> and the balance of Fe and impurities.

The foregoing S355G10 super-thick steel plate for ocean engineering is 120mm thick.

Another object of the present invention is to provide a manufacturing method of the S355G10 super-thick steel plate for ocean engineering, which comprises a steelmaking process, a slab heating process, a rolling process, a controlled cooling process and a tempering process,

Steelmaking process: Deep dephosphorization in a converter is adopted to make the P content in the molten steel be less than or equal to 0.013%, pretreatment and desulfurization of molten iron and LF deep desulfurization are adopted to make the S content in the molten steel be less than or equal to 0.003%, continuous casting adopts dynamic soft reduction and electromagnetic stirring to produce 320mm continuous casting slabs with center segregation of not higher than level C1.0;

Heating process: The casting slabs are heated in a heating furnace, the heating coefficient is 10.0min/cm to 15.0min/cm, and the heating temperature is 1,180 to 1,220 DEG C;

Rolling process: A two-stage controlled rolling process is adopted, the final temperature of the rough rolling in the first stage is more than or equal to 980 DEG C, and the initial rolling temperature in the second stage is less than or equal to 820 DEG C, and the finish rolling temperature is 770 to 810 DEG C;

Cooling process: The rolled steel plate enters an ultra-fast cooling system for rapid cooling, the cooling rate is 10 to 20 DEG C/s, the self-tempering temperature is

520 to 580 DEG C, and then the stacking slow cooling is conducted;

Tempering process: The tempering temperature is 560 to 600 DEG C, the holding time in the furnace is 300min to 400min, and after the tempering, the slabs are stacked separately and air-cooled to room temperature.

5 The present invention has the following beneficial effects:

(1) At 1/2 of the thickness of the steel plate provided by the present invention, the -40 DEG C impact toughness is more than or equal to 150 Akv/J. After 5% strain + 250 DEG C aging, the -40 DEG C impact toughness is more than or equal to 100 Akv/J, and the performance in the thickness direction can reach level Z35. The steel plate  
10 passes the flaw detection according to level S2E3 in the EN10160 standard, and the comprehensive mechanical performance index is up to the same level in foreign countries;

(2) Compared with the super-thick steel plate produced by the heat treatment process of normalization, the present invention adopts a composition design of less  
15 than or equal to 0.38% of CEV and less than or equal to 0.18% of Pcm, lower than those in the normalized steel plate, so the welding performance is more excellent and better meet the requirements for the construction of offshore wind power and ocean platforms and for the application of ultra-large container ships;

(3) The S355G10 super-thick steel plate provided by the present invention meets  
20 the EN10225 standard. It is a steel plate specially designed for offshore structures and has a large market demand and good economic benefits. The gross profit per ton of steel is expected to be more than 1,000 yuan/ton;

(4) In the present invention, the heating process ensures the solid solution of Nb element and the heating uniformity of casting slabs;

25 (5) The steel plate produced by the present invention is 120mm thick at most, the grade of the steel plate is S355G10, its quality meets the requirements of S355G7, S355G8 and S355G9 series grades at the same time, and the production process is also suitable for producing related products with a thickness of not more than 120mm.

## Detailed Description

### Embodiment 1

This embodiment provides an S355G10 super-thick steel plate of 120mm for ocean engineering. The S355G10 super-thick steel plate is prepared from the following chemical components according to mass percent: 0.06% of C, 1.54% of Mn, 0.26% of Si, 0.010% of P, 0.002% of S, 0.027% of Nb, 0.013% of Ti, 0.035% of Al, 0.13% of Cr, 0.41% of Ni, 0.36% of CEV, 0.15% of P<sub>cm</sub> and the balance of Fe and impurities.

Its manufacturing method comprises a steelmaking process, a slab heating process, a rolling process, a controlled cooling process and a tempering process,

Steelmaking process: Deep dephosphorization in a converter is adopted to make the P content in the molten steel be 0.010% of P, pretreatment and desulfurization of molten iron and LF deep desulfurization are adopted to make the S content in the molten steel be 0.002%, continuous casting adopts dynamic soft reduction and electromagnetic stirring to produce 320mm continuous casting slabs with center segregation of level C0.5;

Heating process: The casting slabs are heated in a heating furnace, the heating coefficient is 11.2min/cm, and the heating temperature is 1,203 DEG C;

Rolling process: A two-stage controlled rolling process is adopted, the final temperature of the rough rolling in the first stage is 1,002 DEG C, and the initial rolling temperature in the second stage is 803 DEG C, and the finish rolling temperature is 782 DEG C;

Cooling process: The rolled steel plate enters an ultra-fast cooling system for rapid cooling, the cooling rate is 17 DEG C/s, the self-tempering temperature is 535 DEG C, and then the stacking slow cooling is conducted;

Tempering process: The tempering temperature is 571 DEG C, the holding time in the furnace is 350min, and after the tempering, the slabs are stacked separately and air-cooled to room temperature.

The mechanical properties of this S355G10 steel plate of 120mm: The yield

strength is 361MPa, the tensile strength is 495MPa, the percentage elongation after fracture is 26%, the -40 DEG C impact energy Akv at 1/2 of the thickness is: 210J, 222J and 206J, the -40 DEG C impact energy Akv after 5% strain+250 DEG C aging is: 251J, 144J and 207J, the percentage reduction of area in the thickness direction is: 51%, 59% and 52%, and the steel plate passes the flaw detection according to level S2E3 in the EN10160 standard.

## Embodiment 2

This embodiment provides an S355G10 super-thick steel plate of 120mm for ocean engineering. The S355G10 super-thick steel plate is prepared from the following chemical components according to mass percent: 0.07% of C, 1.48% of Mn, 0.24% of Si, 0.011% of P, 0.002% of S, 0.025% of Nb, 0.015% of Ti, 0.033% of Al, 0.15% of Cr, 0.46% of Ni, 0.37% of CEV, 0.16% of Pcm and the balance of Fe and impurities.

Its manufacturing method comprises a steelmaking process, a slab heating process, a rolling process, a controlled cooling process and a tempering process,

Steelmaking process: Deep dephosphorization in a converter is adopted to make the P content in the molten steel be 0.011% of P, pretreatment and desulfurization of molten iron and LF deep desulfurization are adopted to make the S content in the molten steel be 0.002%, continuous casting adopts dynamic soft reduction and electromagnetic stirring to produce 320mm continuous casting slabs with center segregation of level C1.0;

Heating process: The casting slabs are heated in a heating furnace, the heating coefficient is 10.6min/cm, and the heating temperature is 1,209 DEG C;

Rolling process: A two-stage controlled rolling process is adopted, the final temperature of the rough rolling in the first stage is 992 DEG C, and the initial rolling temperature in the second stage is 807 DEG C, and the finish rolling temperature is 791 DEG C;

Cooling process: The rolled steel plate enters an ultra-fast cooling system for rapid cooling, the cooling rate is 14 DEG C/s, the self-tempering temperature is 564

DEG C, and then the stacking slow cooling is conducted;

Tempering process: The tempering temperature is 586 DEG C, the holding time in the furnace is 386min, and after the tempering, the slabs are stacked separately and air-cooled to room temperature.

5        The mechanical properties of this S355G10 steel plate of 120mm: The yield strength is 347MPa, the tensile strength is 491MPa, the percentage elongation after fracture is 25%, the -40 DEG C impact energy Akv at 1/2 of the thickness is: 215J, 232J and 238J, the -40 DEG C impact energy Akv after 5% strain+250 DEG C aging is: 195J, 180J and 178J, the percentage reduction of area in the thickness direction is:  
10    55%, 49% and 58%, and the steel plate passes the flaw detection according to level S2E3 in the EN10160 standard.

      Among the existing S355G10 steel plates with toughness at low temperature for ocean engineering, the super-thick steel plates with a thickness of 100mm or more are mostly produced by adopting a heat treatment process of normalizing or quenching  
15    and tempering, and steel ingots are used as raw materials for rolling to ensure a large compression ratio. In order to ensure various properties, a large amount of alloy will be added, resulting in a high overall production cost. Further, a high content of C and CEV in the composition design is not favorable to welding performance; the maximum thickness of the steel plates produced according to the TMCP process is only 100mm,  
20    which cannot fully meet the requirements of super-thick steel plates with a thickness of 100mm or more for ocean engineering.

      A low-carbon composition design is adopted and a smelting process technology with ultra-low P and S is applied to obtain high-quality casting slabs with center segregation of levels C0.5 and C1.0. Under the condition of a low compression ratio,  
25    the TMCP process and the subsequent heat treatment process of tempering are adopted to further improve the structural performance of the super-thick steel plate at 1/2 of the thickness and develop a 120mm thick S355G10 super-thick steel plate for ocean engineering, which has good toughness at low temperature. The -40 DEG C impact toughness at 1/2 of the thickness of the steel plate is more than or equal to 150 Akv/J,

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the -40 DEG C impact energy Akv after 5% strain+250 DEG C aging is more than or equal to 100 Akv/J, the performance in the thickness direction is up to level Z35, and the steel plate passes the flaw detection according to level S2E3 in the EN10160 standard.

- 5        In addition to the foregoing embodiments, the present invention may also have other embodiments. All the technical solutions formed by adopting identical replacements or equivalent transformations fall in the scope of protection required by the present invention.

## Claims

1. A manufacturing method of the S355G10 super-thick steel plate for ocean engineering, wherein the manufacturing method of the S355G10 super-thick steel plate for ocean engineering comprises a steelmaking process, a slab heating process, a rolling process, a controlled cooling process, and a tempering process,

steelmaking process: Deep dephosphorization in a converter is adopted to make the P content in the molten steel be less than or equal to 0.013%, pretreatment and desulfurization of molten iron and LF deep desulfurization are adopted to make the S content in the molten steel be less than or equal to 0.003%, continuous casting adopts dynamic soft reduction and electromagnetic stirring to produce 320mm continuous casting slabs with center segregation of not higher than level C1.0;

heating process: The casting slabs are heated in a heating furnace, the heating coefficient is 10.0min/cm to 15.0min/cm, and the heating temperature is 1,180 to 1,220 DEG C;

rolling process: A two-stage controlled rolling process is adopted, the final temperature of the rough rolling in the first stage is more than or equal to 980 DEG C, and the initial rolling temperature in the second stage is less than or equal to 820 DEG C, and the finish rolling temperature is 770 to 810 DEG C;

cooling process: The rolled steel plate enters an ultra-fast cooling system for rapid cooling, the cooling rate is 10 to 20 DEG C/s, the self-tempering temperature is 520 to 580 DEG C, and then the stacking slow cooling is conducted;

tempering process: The tempering temperature is 560 to 600 DEG C, the holding time in the furnace is 300min to 400min, and after the tempering, the slabs are stacked separately and air-cooled to room temperature;

wherein the S355G10 super-thick steel plate is prepared from the following chemical components according to mass percent: 0.04% to 0.08% of C, 1.40% to 1.60% of Mn, 0.10% to 0.30% of Si, less than or equal to 0.013% of P, less than or equal to 0.003% of S, 0.015% to 0.030% of Nb, 0.010% to 0.020% of Ti, 0.020% to 0.055% of Alt (Al total), 0.10% to 0.20% of Cr, 0.30% to 0.50% of Ni, less than or equal to 0.38% of CEV, less than or equal to 0.18% of Pcm, and the balance of Fe and impurities; wherein the steel plate is 120mm thick.

2. The manufacturing method of the S355G10 super-thick steel plate for ocean engineering according to claim 1, wherein the S355G10 super-thick steel plate is prepared from the following chemical components according to mass percent: 0.06% of C, 1.54% of Mn, 0.26% of Si, 0.010% of P, 0.002% of S, 0.027% of Nb, 0.013% of Ti, 0.035% of Al (Al total), 0.13% of Cr, 0.41% of Ni, 0.36% of CEV, 0.15% of Pcm and the balance of Fe and impurities.

3. The manufacturing method of the S355G10 super-thick steel plate for ocean engineering according to claim 1, wherein the S355G10 super-thick steel plate is prepared from the following chemical components according to mass percent: 0.07% of C, 1.48% of Mn, 0.24% of Si, 0.011% of P, 0.002% of S, 0.025% of Nb, 0.015% of Ti, 0.033% of Al (Al total), 0.15% of Cr, 0.46% of Ni, 0.37% of CEV, 0.16% of Pcm and the balance of Fe and impurities.

4. The manufacturing method of the S355G10 super-thick steel plate for ocean engineering according to claim 1, wherein the manufacturing method of the S355G10 super-thick steel plate for ocean engineering comprises a steelmaking process, a slab heating process, a rolling process, a controlled cooling process and a tempering process,

steelmaking process: Deep dephosphorization in a converter is adopted to make the P content in the molten steel be 0.010% of P, pretreatment and desulfurization of molten iron and LF deep desulfurization are adopted to make the S content in the molten steel be 0.002%, continuous casting adopts dynamic soft reduction and electromagnetic stirring to produce 320mm continuous casting slabs with center segregation of level C0.5;

heating process: The casting slabs are heated in a heating furnace, the heating coefficient is 11.2min/cm, and the heating temperature is 1,203 DEG C;

rolling process: A two-stage controlled rolling process is adopted, the final temperature of the rough rolling in the first stage is 1,002 DEG C, and the initial rolling temperature in the second stage is 803 DEG C, and the finish rolling temperature is 782 DEG C;

cooling process: The rolled steel plate enters an ultra-fast cooling system for rapid cooling, the cooling rate is 17 DEG C/s, the self-tempering temperature is 535 DEG C, and then the stacking slow cooling is conducted;

tempering process: The tempering temperature is 571 DEG C, the holding time in the furnace is 350min, and after the tempering, the slabs are stacked separately and air-cooled to room temperature.

5. The manufacturing method of the S355G10 super-thick steel plate for ocean engineering according to claim 1, wherein the manufacturing method of the S355G10 super-thick steel plate for ocean engineering comprises a steelmaking process, a slab heating process, a rolling process, a controlled cooling process and a tempering process,

steelmaking process: Deep dephosphorization in a converter is adopted to make the P content in the molten steel be 0.011%, pretreatment and desulfurization of molten iron and LF deep desulfurization are adopted to make the S content in the molten steel be 0.002%, continuous casting adopts dynamic soft reduction and electromagnetic stirring to produce 320mm continuous casting slabs with center segregation of level C1.0;

heating process: The casting slabs are heated in a heating furnace, the heating coefficient is 10.6min/cm, and the heating temperature is 1,209 DEG C;

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cooling process: The rolled steel plate enters an ultra-fast cooling system for rapid cooling, the cooling rate is 14 DEG C/s, the self-tempering temperature is 564 DEG C, and then the stacking slow cooling is conducted;

tempering process: The tempering temperature is 586 DEG C, the holding time in the furnace is 386min, and after the tempering, the slabs are stacked separately and air-cooled to room temperature.