

S355G10+N HEAVY STEEL PLATE FOR OFFSHORE STRUCTURES AND MANUFACTURING METHOD THEREOF

TECHNICAL FIELD

- 5 **[01]** The present disclosure relates to the technical field of steel smelting, and specifically relates to an S355G10+N heavy steel plate for offshore structures and a manufacturing method thereof.

BACKGROUND

- 10 **[02]** S355G10 steel is a grade in the BSEN10225 standard "Weldable Structural Steels for Offshore Structures" which specifies the chemical composition, mechanical properties and welding properties of the offshore structural steels. China has not yet formulated the standards dedicated to steels for marine engineering. Low-carbon equivalent, micro-alloying, and proper heat treatment processes (such as normalizing) after controlled rolling are mostly
15 adopted in China to develop S355G10+N and S355NL steel plates, which can meet the requirements for the application of some offshore platforms and structural parts.

- [03]** In the development of steels for marine engineering, there are normalizing process to produce S355G10+N steel plate and TMCP process to produce S355G10+M steel plate. For example, the Chinese patent with the publication number of CN 104726769 discloses an
20 S355G10+N steel plate for heavy offshore platforms and a manufacturing method thereof. The ingot mold is cast for steelmaking, and then rolled into a slab, resulting in high steelmaking cost. Due to the solidification of the steel ingot and the effect of penetration of ultra-heavy steel plate rolling, the application of the impact technique at -40 °C and at the 1/2 thickness is difficult, and the quality of flaw detection cannot be guaranteed. the Chinese
25 patent with the publication number of CN 109628853 discloses an S355G10 ultra-heavy steel plate for marine engineering and a manufacturing method thereof, which adopts low-carbon design, TMCP process, and tempering process. Limited by the compression ratio of continuous casting slab, the largest thickness of the steel plate manufactured is 120 mm, which cannot completely meet the needs of ultra-heavy steel plates with the thickness greater
30 than 120 mm for marine engineering.

- [04]** Limited by the compression ratio of existing continuous casting slabs, the S355G10+N heavy steel plates for general offshore structures, such as S355G10+N heavy steel plates with the thickness greater than 100 mm, are mostly rolled using the steel ingot as the raw material to ensure a large compression ratio, with the reason that the rolling

compression ratio required by the EN10225 standard is not less than 4 times. In addition, the normalizing process is adopted. Due to the solidification of the steel ingot and the effect of penetration of ultra-heavy plate rolling, the application of the impact technique at -40 °C and at the 1/2 thickness is difficult, and the quality of flaw detection cannot be guaranteed.

- 5 However, the largest thickness of steel plate manufactured through the TMCP process and the TMCP+tempering process is only 100 mm and 120 mm, which cannot completely meet the needs of ultra-heavy steel plates greater than 120 mm for marine engineering.

SUMMARY

- 10 **[05]** To solve the above technical problems, the present disclosure provides an S355G10+N heavy steel plate for offshore structures. A thickness of the S355G10+N heavy steel plate is up to 150 mm, and the S355G10+N heavy steel plate is composed of the following chemical composition in mass percentage: C: 0.08%-0.14%, Mn: 1.30%-1.65%, Si: 0.10%-0.50%, $P \leq 0.015\%$, $S \leq 0.005\%$, Nb: 0.015%-0.030%, $V \leq 0.03\%$, Ti: 0.10%-
15 0.020%, Al: 0.020%-0.055%, Ni: 0.10%-0.50%, $CEV \leq 0.43\%$, $P_{cm} \leq 0.21\%$, and a balance of Fe and inevitable impurities.

- [06]** The technical effects are as follows: The present disclosure adopts reasonable composition design, composite slab rolling, and normalizing process to develop the S355G10+N heavy steel plate with the maximum thickness of 150 mm specified by the
20 BSEN10225 standard. The impact toughness at -40 °C of the S355G10+N heavy steel plate on the near-surface and at the 1/2 thickness is not less than 100 J, the performance in the thickness direction reaches Z35 level, the flaw detection is qualified according to the S2E3 level in the EN10160 standard, and the comprehensive mechanical properties are as good as those of the same kind of steel plates abroad. In addition, the S355G10+N heavy steel plate
25 has excellent low-temperature toughness and good welding performance.

[07] The technical solution further limited by the present disclosure is as follows:

- [08]** The S355G10+N heavy steel plate for offshore structures is composed of the following chemical composition in mass percentage: C: 0.08%-0.10%, Mn: 1.58%-1.65%, Si: 0.34%-0.50%, $P \leq 0.010\%$, $S \leq 0.002\%$, Nb: 0.015%-0.021%, $V \leq 0.028\%$, Ti: 0.10 %-
30 0.020%, Al: 0.020%-0.031%, Ni: 0.10%-0.31%, $CEV \leq 0.40\%$, $P_{cm} \leq 0.20\%$, and the balance of Fe and inevitable impurities.

[09] The S355G10+N heavy steel plate for offshore structures is composed of the following chemical composition in mass percentage: C: 0.12%-0.14%, Mn: 1.30%-1.41%, Si: 0.10%-0.21%, $P \leq 0.011\%$, $S \leq 0.001\%$, Nb: 0.027%-0.030%, $V \leq 0.03\%$, Ti: 0.10 %-

0.020%, Alt: 0.036%-0.055%, Ni: 0.43%-0.50%, CEV $\leq$ 0.40%, Pcm $\leq$ 0.21%, and the balance of Fe and inevitable impurities.

[10] Another object of the present disclosure is providing a method for manufacturing the S355G10+N heavy steel plate for offshore structures. The method comprises a slab vacuum welding process, a composite slab heating process, a rolling process, and a normalizing process, specifically comprising the following steps:

[11] the slab vacuum welding process: welding two or more continuous casting slabs with the same heat number and the same composition under the condition that a vacuum degree is less than or equal to 0.05 Pa, to obtain a composite slab with a thickness more than 600 mm;

[12] the composite slab heating process: heating the composite slab to 1200-1250 °C for 5-10 h;

[13] the rolling process: performing a two-stage rolling process through a wide and heavy plate mill; wherein, a final rolling temperature for rough rolling is $\geq$ 950 °C, and an initial rolling temperature for finish rolling is $\leq$ 840 °C; and a steel plate obtained is air-cooled after the two-stage rolling process; and

[14] the normalizing process: normalizing the steel plate in a heat treatment furnace at 880-920 °C for $(1.8-2.0) \times H$ min; wherein, H is the thickness of the steel plate with a unit of mm.

[15] The S355G10+N heavy steel plate for offshore structures has the thickness of 150 mm, and is composed of the following chemical composition in mass percentage: C: 0.10%, Mn: 1.58%, Si: 0.34%, P: 0.010%, S: 0.002%, Nb: 0.021%, V: 0.028%, Ti: 0.14%, Alt: 0.031%, Ni: 0.31%, CEV: 0.40%, Pcm: 0.20%, and the balance of Fe and inevitable impurities. The method comprises the following steps:

[16] the slab vacuum welding process: welding two 310 mm continuous casting slabs with the same heat number and the same composition under the condition that the vacuum degree is 0.03 Pa, to obtain a composite slab with a thickness of 620 mm;

[17] the composite slab heating process: heating the composite slab with the thickness of 620 mm to 1243 °C for 8 h;

[18] the rolling process: performing the two-stage rolling process through the wide and heavy plate mill; wherein, the final rolling temperature for the rough rolling is 988 °C, and the initial rolling temperature for the finish rolling is 832 °C; and the steel plate obtained is air-cooled after the two-stage rolling process; and

[19] the normalizing process: normalizing the steel plate in the heat treatment furnace at

892 °C for 279 min.

[20] The S355G10+N heavy steel plate for offshore structures has the thickness of 150 mm, and is composed of the following chemical composition in mass percentage: C: 0.12%, Mn: 1.41%, Si: 0.21%, P: 0.011%, S: 0.001%, Nb: 0.027%, V: 0.03%, Ti: 0.020%, Al: 0.036%, Ni: 0.43%, CEV: 0.40%, P_{cm}: 0.21%, and the balance of Fe and inevitable impurities. The method comprises the following steps:

[21] the slab vacuum welding process: welding two 300 mm continuous casting slabs with the same heat number and the same composition under the condition that the vacuum degree is 0.04 Pa, to obtain a composite slab with a thickness of 600 mm;

[22] the composite slab heating process: heating the composite slab with the thickness of 600 mm to 1234 °C for 7 h;

[23] the rolling process: performing the two-stage rolling process through the wide and heavy plate mill; wherein, the final rolling temperature for the rough rolling is 997 °C, and the initial rolling temperature for the finish rolling is 836 °C; and the steel plate obtained is air-cooled after the two-stage rolling process; and

[24] the normalizing process: normalizing the steel plate in the heat treatment furnace at 905 °C for 293 min.

[25] The beneficial effects of the present disclosure are as follows:

[26] (1) The present disclosure obtains the composite slab with the desired thickness by welding the ordinary continuous casting slabs. Thus, the cost is far lower than that of the ingot steelmaking method, and the production efficiency is high.

[27] (2) The present disclosure uses high-quality continuous casting slabs for welding. The impact toughness at - 40 °C of the steel plate at the 1/2 thickness is better since the 1/2 thickness of the steel plate corresponds to the welding position and the near-surface of the original continuous casting slabs, and the quality of flaw detection is guaranteed.

[28] (3) Compared with the TMCP process and the TMCP+tempering process, the thickness of the steel plate manufactured by the present disclosure is up to 150 mm, which exceeds the maximum thickness of 100 mm and 120 mm manufactured by the continuous casting slabs.

[29] (4) The steel plate with the thickness of 150 mm manufactured by the present disclosure has excellent low-temperature toughness. Particularly, using the 1/2 thickness of the steel plate as the welding position is capable of avoiding the centerline segregation of the original continuous casting slabs. Compared with the slab rolling method, the impact toughness at low temperature of the steel plate at the 1/2 thickness is effectively guaranteed.

The metallographic structure is F + P structure, the grain size is 8.0-9.5, the banded structure is less than or equal to 1.0, and the impact toughness at -40 °C of the steel plate at the 1/2 thickness is greater than 100 J. The steel plate has good welding performance, which better meets the use and service requirements of offshore structures.

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DETAILED DESCRIPTION OF THE EMBODIMENTS

[30] Example 1

[31] This example provides the S355G10+N heavy steel plate for offshore structures with the thickness of 150 mm. The S355G10+N heavy steel plate is composed of the following chemical composition in mass percentage: C: 0.10%, Mn: 1.58%, Si: 0.34%, P: 0.010%, S: 0.002%, Nb: 0.021%, V: 0.028%, Ti: 0.14%, Al: 0.031%, Ni: 0.31%, CEV: 0.40%, Pcm: 0.20%, and the balance of Fe and inevitable impurities.

[32] The manufacturing method includes the following steps:

[33] The slab vacuum welding process: two 310 mm continuous casting slabs with the same heat number and the same composition are welded under the condition that the vacuum degree is 0.03 Pa, to obtain the composite slab with the thickness of 620 mm.

[34] The composite slab heating process: the composite slab with the thickness of 620 mm is heated to 1243 °C for 8 h.

[35] The rolling process: the two-stage rolling process is carried out through the wide and heavy plate mill. The final rolling temperature for the rough rolling is 988 °C, and the initial rolling temperature for the finish rolling is 832 °C. The steel plate obtained is air-cooled after the two-stage rolling process.

[36] The normalizing process: the steel plate is normalized in the heat treatment furnace at 892 °C for 279 min.

[37] The mechanical properties of the steel plate are as follows: the yield strength is 347 MPa; the tensile strength is 498 MPa; the elongation at break is 30%; the yield-to-tensile ratio is 0.70; the impact energy (Ak_v) at -40 °C of the steel plate on the near-surface is 134 J, 180 J, and 152 J; the impact energy (Ak_v) at -40 °C of the steel plate at the 1/2 thickness is 209 J, 207 J, and 218 J; the reduction of area in the thickness direction is 61%, 56%, and 55%; and the flaw detection is qualified according to the S2E3 level in the EN10160 standard.

[38] Example 2

[39] This example provides the S355G10+N heavy steel plate for offshore structures with the thickness of 150 mm. The S355G10+N heavy steel plate is composed of the following chemical composition in mass percentage: C: 0.12%, Mn: 1.41%, Si: 0.21%, P: 0.011%, S:

0.001%, Nb: 0.027%, V: 0.03%, Ti: 0.020%, Al: 0.036%, Ni: 0.43%, CEV: 0.40%, Pcm: 0.21%, and the balance of Fe and inevitable impurities.

[40] The manufacturing method includes the following steps:

[41] The slab vacuum welding process: two 300 mm continuous casting slabs with the same heat number and the same composition are welded under the condition that the vacuum degree is 0.04 Pa, to obtain the composite slab with the thickness of 600 mm.

[42] The composite slab heating process: the composite slab with the thickness of 600 mm is heated to 1234 °C for 7 h.

[43] The rolling process: the two-stage rolling process is carried out through the wide and heavy plate mill. The final rolling temperature for the rough rolling is 997 °C, and the initial rolling temperature for the finish rolling is 836 °C. The steel plate obtained is air-cooled after the two-stage rolling process.

[44] The normalizing process: the steel plate is normalized in the heat treatment furnace at 905 °C for 293 min.

[45] The mechanical properties of the steel plate are as follows: the yield strength is 342 MPa; the tensile strength is 489 MPa; the elongation at break is 28%; the yield-to-tensile ratio is 0.70; the impact energy (Ak_v) at -40 °C of the steel plate on the near-surface is 163 J, 192 J, and 185 J; the impact energy (Ak_v) at -40 °C of the steel plate at the 1/2 thickness is 226 J, 196 J, and 198 J; the reduction of area in the thickness direction is 57%, 60%, and 64%; and the flaw detection is qualified according to the S2E3 level in the EN10160 standard.

[46] As the exploration of marine resources continues to expand towards the deep sea, the demand for steels such as ultra-heavy steel plates and large-sized steel plates for marine engineering is increasingly growing. The S355G10 steel plate manufactured according to the EN10225 standard is a steel plate dedicated to offshore structures with large market demand. Compared with the steel ingot blooming and rolling method, the application of the impact technique at -40 °C of the steel plate at the 1/2 thickness is difficult due to the solidification of the steel ingot and the effect of penetration of ultra-heavy plate rolling, and the quality of flaw detection cannot be guaranteed. The present disclosure adopts reasonable composition design, composite slab rolling, and normalizing process to develop the S355G10+N heavy steel plate with the maximum thickness of 150 mm specified by the BSEN10225 standard. The impact toughness at -40 °C of the S355G10+N heavy steel plate on the near-surface and at the 1/2 thickness is not less than 100 J, the performance in the thickness direction reaches Z35 level, the flaw detection is qualified according to the S2E3 level in the EN10160 standard, and the comprehensive mechanical properties are as good as

those of the same kind of steel plates abroad.

[47] The maximum thickness of the S355G10+N heavy steel plate manufactured by the present disclosure is 150 mm, and the process is also suitable for the manufacture of related products with the thickness not more than 150 mm. The quality of S355G10+N heavy steel plate meets the requirements of S355G7+N, S355G8+N, and S355G9+N grades. The S355G10+N heavy steel plate has excellent low-temperature toughness and excellent welding performance due to the low content of CEV and Pcm in the composition design. The S355G10+N heavy steel plate of the present disclosure can better meet the requirement for the application of offshore wind power, offshore platform construction, and ultra-large container ships. Thus, the economic benefits are good, and it is estimated that the gross profit per ton of steel is more than 1,000 yuan/ton.

[48] In addition to the above-mentioned examples, the present disclosure may also have other examples. All technical solutions formed by equivalent replacements or transformations shall fall within the protection scope of the present disclosure.

Claims

1. An S355G10+N heavy steel plate for offshore structures, produced by a method comprising:

a slab vacuum welding process that comprises welding two or more continuous casting slabs with the same heat number and the same composition under the condition that a vacuum degree is less than or equal to 0.05 Pa, resulting in a composite slab with a thickness more than 600 mm;

a composite slab heating process that comprises heating the composite slab to 1200-1250 °C for 5-10 h;

a rolling process that comprises performing a two-stage rolling process through a wide and heavy plate mill, with a final rolling temperature for rough rolling of ≥ 950 °C, and an initial rolling temperature for finish rolling of ≤ 840 °C, followed by air-cooling of the steel plate obtained;

a normalizing process that comprises normalizing the steel plate in a heat treatment furnace at 880-920 °C for $(1.8-2.0) \times H$ min, where H is the thickness of the steel plate with a unit of mm;

wherein, the S355G10+N heavy steel plate has the following chemical composition in mass percentage: C: 0.08%-0.10%, Mn: 1.30%-1.65%, Si: 0.10%-0.50%, $P \leq 0.015\%$, $S \leq 0.005\%$, Nb: 0.015%-0.030%, $V \leq 0.03\%$, Ti: 0.020%-0.10%, Al total or Al_T: 0.020%-0.055%, Ni: 0.10%-0.50%, Carbon Equivalent Value or CEV $\leq 0.43\%$, cold cracking susceptibility index or $P_{cm} \leq 0.21\%$, and a balance of Fe and inevitable impurities; and

wherein an impact toughness at -40 °C of the steel plate at 1/2 thickness is greater than 100 J and wherein a thickness of the S355G10+N heavy steel plate is up to 150 mm.

2. The S355G10+N heavy steel plate for offshore structures according to claim 1, wherein, the S355G10+N heavy steel plate is composed of the following chemical composition in mass percentage: C: 0.08%-0.10%, Mn: 1.58%-1.65%, Si: 0.34%-0.50%, $P \leq 0.010\%$, $S \leq 0.002\%$, Nb: 0.015%-0.021%, $V \leq 0.028\%$, Ti: 0.020 %-0.10%, Al total or Alt: 0.020%-0.031%, Ni: 0.10%-0.31%, Carbon Equivalent Value or CEV $\leq 0.40\%$, cold cracking susceptibility index or Pcm $\leq 0.20\%$, and the balance of Fe and inevitable impurities.

3. The S355G10+N heavy steel plate for offshore structures according to claim 1, wherein the steel plate has a thickness of 150mm, and is produced by a method comprising:

a slab vacuum welding process, that comprises using two 310mm continuous casting slabs of the same batch number and composition, welding under a vacuum of 0.03 Pa to obtain a welded composite slab with a thickness of 620mm;

a composite billet heating process, that comprises heating the slab to 1243°C, holding for 8h;

a rolling process, that comprises performing a rolling in two stages through a wide and thick plate rolling mill, with the final rolling temperature of the rough rolling stage being 988°C, and the starting rolling temperature of the finishing rolling stage being 832°C, followed by air cooling of the steel plate obtained;

a normalization heat treatment process, wherein the steel plate is normalized in a heat treatment furnace, with the normalization temperature being 892°C, and the holding time being 279 minutes;

wherein the S355G10+N heavy has the following chemical composition in mass percentage: C: 0.10%, Mn: 1.58%, Si: 0.34%, P: 0.010%, S: 0.002%, Nb: 0.021%, V: 0.028%, Ti: 0.14%, Al: 0.031%, Ni: 0.31%, CEV: 0.40%, Pcm: 0.20%, with the remainder being Fe and unavoidable impurities.