

460 MPA-GRADE EXTRA-THICK HOT-ROLLED H-SHAPED STEEL AND PRODUCTION METHOD THEREFOR

[0001] This application claims priority to Chinese Patent Application No. 202311592693.3,
5 titled “460 MPA-GRADE EXTRA-THICK HOT-ROLLED H-SHAPED STEEL AND
PRODUCTION METHOD THEREFOR”, filed on November 27, 2023 with the China National
Intellectual Property Administration, which is incorporated herein by reference in its entirety.

FIELD

10 **[0002]** The present disclosure relates to the technical field of hot-rolled H-section steel
production, and in particular to a 460MPa-grade extra-thick hot-rolled H-section steel and a
production method thereof.

BACKGROUND

15 **[0003]** Extra-thick hot-rolled H-section steel refers to hot-rolled H-section steel with a flange
thickness greater than 60mm. In the production of extra-thick hot-rolled H-section steel, due to
constraints of production equipment and related technologies, ultra-large beam blanks with a
flange thickness of 150mm to 210mm are typically adopted as blanks. The quality control of
such beam blanks during casting is far more difficult than that of small to medium-sized beam
20 blanks, resulting in large fluctuations in the mechanical properties of finished extra-thick hot-
rolled H-section steel products.

[0004] In addition, as the flange thickness of hot-rolled H-section steel products increases,
the difficulty in improving the mechanical properties of the products becomes greater due to
the thickness effect. At present, the yield strength of extra-thick hot-rolled H-section steel with
25 the flange thickness greater than 60mm is mainly at the 355MPa grade, while the 460MPa grade
is still unavailable.

[0005] With the increasing construction of super high-rise buildings, long-span bridges and
large venues, 460MPa-grade extra-thick hot-rolled H-section steel will become a key material
for their supporting structures. In summary, extra-thick high-strength hot-rolled H-section steel

has broad application prospects, yet the related production technology remains undeveloped. Therefore, aiming at the deficiencies of the existing technology, it is urgent to develop a set of key production technologies for such products.

[0006] A patent with publication number CN104630625A, published on May 20, 2015, discloses a low-temperature-resistant hot-rolled H-section steel and a preparation method thereof. The chemical composition of the hot-rolled H-section steel (wt%) is: C: 0.07% to 0.10%, Si: 0.2% to 0.4%, Mn: 1.30% to 1.60%, $P \leq 0.020\%$, $S \leq 0.015\%$, V: 0.015% to 0.070%, Ti: 0.010% to 0.030%, with the balance being Fe and inevitable impurities. The production method includes converter smelting, ladle furnace (LF) refining, continuous casting, rolling, and the like. The structure of the H-section steel prepared by the invention is polygonal ferrite and pearlite structure, with a yield strength of 350MPa to 450MPa. The rolling process of the patent adopts conventional methods, and the chemical composition design enables the post-rolling yield strength to reach 450MPa, the elongation after fracture to be greater than 22%, and the V-type impact energy at -40°C to be greater than 200J. The method of the invention is applicable to the production of high-strength low-temperature resistant hot-rolled H-section steel with a thickness of less than 40mm, and is not applicable to the production of 460MPa-grade extra-thick hot-rolled H-section steel with a thickness of more than 60mm.

[0007] A patent with publication number CN110016611A, published on July 16, 2019, discloses a weather-resistant and low-temperature resistant hot-rolled H-section steel with a yield strength of 355MPa. The chemical composition by mass percentage includes: C: 0.08% to 0.14%, Si: 0.35% to 0.50%, Mn: 1.00% to 1.15%, $P \leq 0.020\%$, $S \leq 0.015\%$, Cr: 0.40% to 0.50%, Cu: 0.30% to 0.40%, Ni: 0.30% to 0.40%, Nb: 0.03% to 0.05%, Al: 0.020% to 0.040%, with the balance being Fe and impurities, and the total mass fraction is 100%. The patent further discloses a method for producing the weather-resistant and low-temperature resistant hot-rolled H-section steel with a yield strength of 355MPa by using a 280mm×380mm rectangular blank, and successfully develops weather-resistant hot-rolled H-section steel with good low-temperature toughness by using the rectangular blank. The method of the invention adds 0.30% to 0.40% Ni, 0.40% to 0.50% Cr and 0.30% to 0.40% Cu, and the produced hot-rolled H-section steel has good weather resistance and low-temperature toughness, but its strength grade is only 355MPa, which is not applicable to the production of 460MPa-grade extra-thick hot-rolled H-section steel with a thickness of more than 60mm.

[0008] A patent with publication number CN108642381A, published on October 12, 2018, discloses a hot-rolled high-toughness low-temperature resistant H-section steel with a yield strength of 460MPa and a preparation method thereof. The H-section steel involved in the patent adopts a nitrogen-containing composite microalloying component design, and its chemical composition by weight percentage is: C: 0.03% to 0.07%, Si $\leq$ 0.3%, Mn: 1.20% to 1.40%, Nb: 0.015% to 0.030%, V: 0.10% to 0.15%, Ti: 0.015% to 0.025%, Ni: 0.25% to 0.45%, Cr: 0.30% to 0.50%, Als: 0.01% to 0.06%, N: 0.010% to 0.023%, P $\leq$ 0.015%, S $\leq$ 0.010%, O $\leq$ 0.004%, with the balance being Fe and inevitable impurities. Thus, a strength level of 460MPa and above is achieved on a conventional hot-rolled H-section steel mill while obtaining high strength and toughness. After rolling, the yield strength can reach 460MPa, the tensile strength can reach 600MPa, the elongation is $\geq$ 18%, and the longitudinal impact energy at -40°C can reach 100J. The method of the invention adds 0.015% to 0.030% Nb, 0.10% to 0.15% V, 0.015% to 0.025% Ti, 0.25% to 0.45% Ni and 0.30% to 0.50% Cr, and its strength grade can reach 460MPa, and the longitudinal impact energy at -40°C can reach 100J. However, the component design has high cost and poor economy, which is not conducive to industrial actual production.

[0009] A patent with publication number CN103966507A, published on August 6, 2014, discloses an extra-thick low-temperature resistant hot-rolled H-section steel with a yield strength of 275MPa and a production method thereof, with a flange thickness ranging from 26mm to 35mm. The chemical compositions by weight percentage are: C: 0.12% to 0.17%, Si: 0.10% to 0.30%, Mn: 0.90% to 1.40%, P $\leq$ 0.02%, S $\leq$ 0.015%, V: 0.01% to 0.03%, Ti: 0.005% to 0.020%, with the balance being Fe and inevitable impurities. The mechanical properties and the longitudinal impact energy at -20°C of the 275MPa-grade extra-thick low-temperature resistant hot-rolled H-section steel provided by the invention can fully meet the technical requirements of the 275MPa-grade extra-thick low-temperature resistant hot-rolled H-section steel. The hot-rolled H-section steel produced by the method has a thickness of 26mm to 35mm and a strength grade of 275MPa, and is not applicable to the production of 460MPa-grade extra-thick hot-rolled H-section steel with a thickness of more than 60mm.

[0010] A patent with publication number CN109972042A, published on July 5, 2019, discloses an low-temperature resistant and corrosion-resistant H-section steel with a yield strength of 800MPa and a preparation method thereof. The chemical composition by mass percentage (%) is: C: 0.10 to 0.20; Si: 0.20 to 0.40; Mn: 1.20 to 1.60; Ni: 0.2 to 0.4; Cr: 0.2 to

0.6; V: 0.06 to 0.10; Nb: 0 to 0.04; Ti: 0.01 to 0.02; N: 100ppm to 150ppm, $P \leq 0.020$, $S \leq 0.020$, with the balance being Fe and inevitable impurities. The preparation process involves first blank making, then hot rolling, and then quenching and tempering after hot rolling. The hot rolling temperature is 1180°C to 1150°C, and the finishing rolling temperature is 800°C to 890°C. The quenching temperature is 900°C, and the cooling rate is 30°C/s to 100°C/s. The tempering temperature is 450°C to 600°C. The obtained H-section steel has a yield strength of ≥ 800 MPa, a tensile strength of 860MPa to 940MPa, an elongation after fracture ≥ 14.0 , and a low-temperature impact energy at -20°C of ≥ 50 J. The hot-rolled H-section steel produced by the method can achieve a yield strength of up to 800MPa, but it adopts a tempering process, which will undoubtedly increase the production cost.

[0011] A patent with publication number CN103938079A, published on July 23, 2014, discloses an ultra-thick specification low-temperature resistant hot-rolled H-section steel with a low compression ratio and a production method thereof. The H-section steel consists of the following chemical components by weight percentage: C: 0.11% to 0.19%, Si: 0.15% to 0.30%, Mn: 1.30% to 1.55%, $P \leq 0.02\%$, $S \leq 0.008\%$, Ti: 0.008% to 0.020%, V: 0.015% to 0.055%, with the balance being Fe and inevitable impurities. The production method of the H-section steel sequentially includes converter or electric furnace smelting, LF refining, full protective continuous casting of beam blanks, heating, rolling and cooling processes, finally obtaining a low-temperature hot-rolled H-section steel with a flange thickness of about 35mm, a compression ratio of $2.5 < r < 3.0$ and good surface quality, with the average longitudinal impact energy at -20°C of more than 150J, which has broad market application prospects. The hot-rolled H-section steel produced by the method has a maximum flange thickness of 35mm and a minimum compression ratio of 2.5, and its flange thickness is less than 60mm. Therefore, the method is not applicable to the production of 460MPa-grade extra-thick hot-rolled H-section steel with a thickness of more than 60mm.

[0012] Therefore, it is necessary to provide a low-cost and high-performance 460MPa-grade extra-thick hot-rolled H-section steel.

SUMMARY

[0013] The purpose of the present application is to provide a 460MPa-grade extra-thick hot-rolled H-section steel and a production method thereof. Through component optimization

combined with matching process parameters, the hot-rolled H-section steel with a flange thickness of 60mm to 140mm is obtained. The product has a yield strength R_{eH} of 466MPa to 493MPa, a tensile strength of 613MPa to 680MPa, an elongation of 22.0% to 26.5%, and an impact value at -20°C of 78J to 106J. The production difficulties of extra-thick high-strength hot-rolled H-section steel are solved, and the components are low and the performance is excellent.

[0014] The specific technical solution of the present application is as follows.

[0015] A 460MPa-grade extra-thick hot-rolled H-section steel, comprising the following components by mass percentage:

C: 0.10% to 0.20%, Si: 0.30% to 0.50%, Mn: 0.8% to 1.50%, $P \leq 0.015\%$, $S \leq 0.005\%$, Nb: 0.010% to 0.050%, V: 0.040% to 0.100%, Ti: 0.006% to 0.020%, Cr: 0.10% to 0.30%, N: 0.0060% to 0.0120%, with the balance being Fe and inevitable impurities.

[0016] The components of the 460MPa-grade extra-thick hot-rolled H-section steel satisfy: $0.35\% \leq C + Mn/6 \leq 0.45\%$.

[0017] The components of the 460MPa-grade extra-thick hot-rolled H-section steel satisfy: $0.060\% \leq Nb + V \leq 0.130\%$.

[0018] Through the above formulas, it is ensured that the steel has sufficient strength and toughness. In a case that $C + Mn/6$ is too low, the carbon equivalent will be too low. A low carbon equivalent weakens the solid solution strengthening effect of C and Mn in the steel, which is unfavorable to the strength improvement of the steel, and even difficult to meet the strength requirements. In a case that $C + Mn/6$ is too high, the welding performance of the steel is affected, i.e., the weldability is poor. In an embodiment, C is: 0.10% to 0.20%, Mn is: 0.8% to 1.50%, and $0.35\% \leq C + Mn/6 \leq 0.45\%$. In order to ensure that the steel has sufficient strength and good welding performance, the composite addition of Nb+V has a better effect. Adding Nb alone has a good toughness improvement effect, but the strengthening effect is limited. Adding V alone has a good strengthening effect, but the toughness improvement is limited. In a case that the total amount of Nb+V is too low, the strength and toughness of the steel are insufficient. In a case that the total amount is too high, especially the content of Nb is too high, the high-temperature plasticity of the steel will decrease significantly, and crack defects are prone to occur during the production process. In order to ensure sufficient strength and toughness and

ensure the surface quality of the steel, Nb is: 0.010% to 0.050%, V is: 0.040% to 0.100%, and $0.060\% \leq \text{Nb} + \text{V} \leq 0.130\%$.

[0019] In the calculation formula, the value indicated by each element = the content of the element in the steel $\times 100$.

5 **[0020]** In an embodiment, the Nb content of the 460MPa-grade extra-thick hot-rolled H-section steel should be controlled at 0.020% to 0.040%. The Nb element in the range can prevent the growth of prior austenite grains during the heating process of the cast blank, thereby refining the ferrite grain size and improving the strength and toughness of the steel. An excessively low Nb content is unfavorable to the strength and toughness of the steel, and an
10 excessively high Nb content is unfavorable to the plasticity of the steel.

[0021] In an embodiment, the V content of the 460MPa-grade extra-thick hot-rolled H-section steel should be controlled at 0.060% to 0.100% to ensure that the precipitation strengthening effect after rolling is better exerted. Too low V content is unfavorable to the strength of the steel, and too high V content is unfavorable to the toughness of the steel.

15 **[0022]** In an embodiment, the Ti content of the 460MPa-grade extra-thick hot-rolled H-section steel should be controlled at 0.008% to 0.015%. Ti is more difficult to dissolve than Nb and V elements during the heating process of the cast blank, and it inhibits the growth of prior austenite grains more effectively. In addition, the fine precipitates of Ti after rolling can pin dislocations more significantly and play a higher strengthening role. In addition, the precipitates
20 of Nb generally precipitate along the Ti precipitates, which can realize the soft phase wrapping the hard phase, thereby effectively enhancing the toughness of the steel. Too low Ti content results in too few Ti precipitates, which is unfavorable to the strength. Too high Ti content results in too large precipitates, which is unfavorable to the plasticity and toughness of the steel.

[0023] In an embodiment, the N content of the 460MPa-grade extra-thick hot-rolled H-section steel should be controlled at 0.0080% to 0.0100% to ensure the formation of a sufficient
25 amount of fine and uniform carbonitrides with Nb, V and Ti. Furthermore, the N element can further appropriately improve the hardenability of the steel. Too low N content is insufficient to form a sufficient amount of carbonitrides of Nb, V and Ti, thereby hindering the effective role of the microalloying elements, and too high N content is prone to cracking.

[0024] In an embodiment, the Cr content of the 460MPa-grade extra-thick hot-rolled H-section steel should be controlled at 0.20% to 0.30% to increase the hardenability of the steel after rolling. Too low Cr content is unfavorable to the strength of the steel, and too high Cr content is unfavorable to the plasticity and toughness of the steel.

5 **[0025]** The flange structure of the 460MPa-grade extra-thick hot-rolled H-section steel is as follows: 2mm from the surface layer is tempered sorbite; the core is ferrite + pearlite. The area ratio of the ferrite is $80\pm 2\%$, the area ratio of pearlite is $20\pm 2\%$, and the grain size grade is ≥ 8.0 .

[0026] The 460MPa-grade extra-thick hot-rolled H-section steel has a flange thickness of 60mm to 140mm.

10 **[0027]** The 460MPa-grade extra-thick hot-rolled H-section steel has a yield strength R_{eH} of 466 MPa to 493MPa, a tensile strength of 613MPa to 680MPa, an elongation of 22.0% to 26.5%, and an impact value at -20°C of 78J to 106J.

[0028] The present application provides a method for producing 460MPa-grade extra-thick hot-rolled H-section steel, comprising stack cooling after casting and withdrawal of a blank;
15 then heating, and controlled rolling and controlled cooling.

[0029] The cast blank has the flange thickness of 180mm to 210mm.

[0030] For the stack cooling, the stack cooling is carried out for a duration t_d of > 5 h, which can effectively reduce the hydrogen content in the blank and prevent hydrogen accumulation which would otherwise lead to low elongation or disqualification.

20 **[0031]** In an embodiment, the duration t_d of the stack cooling and a temperature T_d of the blank before entering the stack cooling zone satisfy a relational expression:

$$t_d = -10.16 + \left(\frac{62464.91}{2464.65 \times \sqrt{\pi / 2}} \times e^{-2((T_d - 1741.20) / 2464.25)^2} \right)$$
. The temperature T_c of the blank when exiting the stack cooling zone is controlled at 400°C to 500°C , and the duration t_d of the stack cooling is controlled at > 5 h. The temperature T_d of the blank before entering the stack cooling zone is
25 generally 900°C to 1300°C . The duration t_d of the stack cooling that is too short hinders hydrogen diffusion and adversely affects the tensile properties of the steel, and the duration t_d of the stack cooling that is too long is unfavorable to production efficiency.

[0032] The unit of the duration t_d of the stack cooling is hour, h. The unit of temperature T_d of the blank before entering the stack cooling zone is °C. In the above formula calculation, the data before the above units are substituted into the formula for calculation.

[0033] For the heating, the blank after stack cooling is sent to a heating furnace for heating, the heating is controlled at a duration of 120min to 180min, the heating furnace is controlled at a temperature of 1200°C to 1250°C; a discharging temperature is 1200°C to 1250°C.

[0034] In an embodiment, the heating should be controlled at a duration of 130min to 150min. Too short heating duration results in that the carbonitrides of Nb, V and Ti cannot be completely dissolved in austenite, and the undissolved second-phase particles are easy to be too large when precipitated after rolling, which has no obvious contribution to the mechanical properties and even is harmful. Excessively long heating duration leads to coarsening of the size of prior austenite grains, which is unfavorable to the mechanical properties of the product.

[0035] In the present application, the heating temperature should be controlled at 1200°C to 1250°C. Too low heating temperature results in that the carbonitrides of Nb, V and Ti cannot be completely dissolved in austenite, and the undissolved second-phase particles are easy to be too large when precipitated after rolling, which has no apparent contribution to the mechanical properties and even is harmful. Too high heating temperature leads to coarsening of the size of prior austenite grains, which is unfavorable to the mechanical properties of the product.

[0036] For the controlled rolling and controlled cooling, a universal rolling stage is carried out after a breakdown rolling stage.

[0037] For the universal rolling stage, a flange cooling device is activated in the 1st to 4th passes to perform controlled cooling on a flange, with a flange cooling rate of 15°C /s to 30°C /s, and the temperature after cooling is controlled at 960°C to 980°C. In the 2nd pass of universal rolling, temperature-controlled rolling is adopted, and a start rolling temperature for a web is controlled at 900°C to 950°C.

[0038] After the process in the universal rolling stage is completed, post-rolling controlled cooling is carried out through a rapid cooling device, a start cooling temperature is controlled at 900°C to 950°C, a flange cooling rate is controlled at 30°C/s to 50°C/s, and a surface temperature of the steel after controlled cooling is controlled at 400°C to 500°C.

[0039] In an embodiment, the flange cooling rate in the 1st to 4th passes is controlled at 20°C/s to 25°C/s. Too high cooling rate results in excessive rolling pressure and large equipment loss. Too low cooling rate is not conducive to the improvement of the mechanical properties of the steel.

5 **[0040]** In an embodiment, the start temperature for rolling in the 2nd pass of universal rolling should be controlled at 920°C to 940°C. Too low start temperature for rolling will lead to excessive rolling pressure and great damage to equipment. Too high start temperature for rolling is not conducive to grain refinement and is unfavorable to the mechanical properties of the steel.

[0041] In an embodiment, the start cooling temperature is controlled at 910°C to 930°C. Too
10 low start temperature for controlled cooling is unfavorable to both the strength and toughness of the steel. Too high start temperature for controlled cooling is unfavorable to the toughness of the steel.

[0042] In an embodiment, in the post-rolling controlled cooling, the cooling rate should be controlled at 35°C/s to 45°C/s, and the surface temperature of the steel after controlled cooling
15 is controlled at 430°C to 460°C. The temperature after controlled cooling is the self-tempering temperature of the extra-thick H-section steel. Too low temperature is unfavorable to the toughness of the steel. Too high temperature is unfavorable to both the strength and toughness of the steel.

[0043] After the controlled rolling and controlled cooling, the product is sent to a cooling bed
20 and then naturally cooled. The heat in the core is gradually conducted to the subsurface layer and surface layer, such that the subsurface layer and surface layer metals after controlled cooling realize self-tempering, thereby improving their mechanical properties.

[0044] Compared with the conventional technology, in the steelmaking process of the present application, the grain size of the blank is finer and more uniform through a specific component
25 design. After continuous casting of the blank, a blank slow cooling zone is provided to perform slow cooling of the stacked blanks after withdrawal with a specific process, so that the hydrogen inside the blank is effectively diffused out of the blank. A specific controlled rolling and controlled cooling process is adopted in the rolling zone. When producing the hot-rolled H-section steel with the flange thickness of 60mm to 140mm by the method of the present
30 disclosure, the product has a yield strength ReH of 466 MPa to 493MPa, a tensile strength of 613 MPa to 680MPa, an elongation of 22.0% to 26.5%, and an impact value at -20°C of 78 J to

106J. The metallographic structure of the product is shown in FIG. 2, which shows that its surface layer is tempered sorbite, the core is ferrite + pearlite, the grain size is Grade 8.0, and no white spots is shown on the fracture of the tensile sample.

5 BRIEF DESCRIPTION OF THE DRAWINGS

[0045] FIG. 1 is a schematic diagram of stack cooling of beam blanks according to the present application; conventional stack cooling is performed, with windbreak walls having heat insulation cotton installed at the bottom, top and surrounding areas, and the blanks are naturally slowly cooled in the stack cooling zone.

10 **[0046]** FIG. 2 is a metallographic structure of a hot-rolled H-section steel according to the present application.

[0047] FIG. 3 is a fracture of the tensile sample of a hot-rolled H-section steel, wherein (a) is obtained by a method of the present application, and (b) is obtained by a method not according to the present application.

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DETAILED DESCRIPTION OF EMBODIMENTS

[0048] The specific embodiments of the present application are described in further detail below through description of the examples:

[0049] Examples 1-5

20 **[0050]** A 460MPa-grade extra-thick hot-rolled H-section steel was provided, comprising the following components by mass percentage as shown in Table 1, with the balance not shown in Table 1 being Fe and inevitable impurities.

[0051] Comparative Examples 1-2

25 **[0052]** A 460MPa-grade extra-thick hot-rolled H-section steel was provided, comprising the following components by mass percentage as shown in Table 1, with the balance not shown in Table 1 being Fe and inevitable impurities.

[0053] Table 1 Chemical composition and content of H-section steel in each Example and Comparative Example (wt%)

Item	C	Si	Mn	P	S	Nb	V	Ti	Cr	N	C+ Mn/ 6	Nb+ V
Example 1	0.20	0.38	1.45	0.010	0.003	0.024	0.061	0.010	0.15	0.008	0.4 4	0.08 5
Example 2	0.16	0.32	1.28	0.008	0.001	0.022	0.090	0.012	0.18	0.010	0.3 7	0.11 2
Comparative Example 1 (C+Mn not satisfied)	0.14	0.41	1.22	0.006	0.003	0.025	0.090	0.011	0.18	0.008	0.3 4	0.11 5
Comparative Example 2 (Nb+V not satisfied)	0.17	0.40	1.49	0.011	0.002	0.015	0.040	0.012	0.16	0.009	0.4 2	0.05 5
Comparative Example 3 (Insufficient stack cooling duration)	0.16	0.40	1.48	0.007	0.001	0.023	0.070	0.008	0.20	0.007	0.4 1	0.09 3
Comparative Example 4 (Insufficient heating duration)	0.17	0.35	1.46	0.011	0.002	0.015	0.070	0.012	0.17	0.009	0.4 1	0.08 5
Comparative Example 5 (Excessively long heating duration)	0.17	0.35	1.46	0.011	0.002	0.015	0.070	0.012	0.17	0.009	0.4 1	0.08 5
Comparative Example 6 (Insufficient furnace temperature)	0.19	0.37	1.32	0.005	0.001	0.015	0.050	0.012	0.13	0.011	0.4 1	0.06 5
Comparative Example 7 (Excessively high furnace temperature)	0.19	0.37	1.32	0.005	0.001	0.015	0.050	0.012	0.13	0.011	0.4 1	0.06 5
Comparative Example 8	0.17	0.44	1.41	0.007	0.002	0.018	0.075	0.012	0.18	0.007	0.4 1	0.09 3

(No flange cooling in universal rolling)												
Comparative Example 9 ((High temperature-controlled rolling temperature in universal rolling)	0.18	0.43	1.32	0.012	0.002	0.025	0.060	0.012	0.22	0.008	0.40	0.085
Comparative Example 10 (Low cooling rate in post-rolling controlled cooling of universal rolling)	0.15	0.46	1.39	0.010	0.003	0.019	0.10	0.012	0.15	0.010	0.38	0.119
Comparative Example 11 (High cooling rate in post-rolling controlled cooling of universal rolling)	0.15	0.46	1.39	0.010	0.003	0.019	0.10	0.012	0.15	0.010	0.38	0.119

[0054] Each of the above Examples and Comparative Examples was produced according to the following method, comprising stack cooling after casting and withdrawal of the blank; then heating, and controlled rolling and controlled cooling.

[0055] After casting and withdrawal of the blank, the stack cooling was carried out for a duration of >5 h. In an embodiment, the duration t_d for stack cooling and the temperature T_d of the blank before entering the stack cooling zone satisfied the relational expression:

$$t_d = -10.16 + \left(\frac{62464.91}{2464.65 \times \sqrt{\pi / 2}} \times e^{-2((T_d - 1741.20) / 2464.25)^2} \right)$$
. The temperature T_c of the blank when exiting the stack cooling zone was controlled at 400°C to 500°C, and the duration t_d for stack cooling

was controlled at >5 h. The temperature T_d of the blank before entering the stack cooling zone was generally 900°C to 1300°C . The blank after stack cooling was sent into the heating furnace for heating. The heating time was controlled at 120min to 180min, the temperature in the furnace was controlled at 1200°C to 1250°C ; the discharging temperature was 1200°C to 1250°C , and there were no special requirements for the specific process of the breakdown rolling stage. In the universal rolling stage, a flange cooling device should be activated in the 1st to 4th passes to perform controlled cooling on the flange, the cooling rate was 15°C/s to 30°C/s , and the temperature after cooling was controlled at 960°C to 980°C . In the 2nd pass of universal rolling, the temperature-controlled rolling was adopted, that is, a start rolling temperature for web was controlled at 900°C to 950°C . After a rolling process in the universal rolling stage was completed, post-rolling controlled cooling was carried out through a rapid cooling device. The start cooling temperature was controlled at 900°C to 950°C , the cooling rate was 30°C/s to 50°C/s , and the surface temperature of the steel after controlled cooling was controlled at 400°C to 500°C . Each Example and Comparative Example is specifically controlled according to parameters in Table 2.

[0056] Table 2 Main process parameters of each Example and Comparative Example

Item	Durati on t_d for stack cooling /h	Temper ature T_d before enterin g the stack cooling zone $^{\circ}\text{C}$	Temper ature T_c of blank when exiting the stack cooling zone $^{\circ}\text{C}$	Heati ng time/ min	Temper ature in furnace $^{\circ}\text{C}$	Cooli ng rate of flang e/ $^{\circ}\text{C}$ /s	Start rolling temper ature in the 2 nd pass of univers al rolling $^{\circ}\text{C}$	Start cooling temper ature $^{\circ}\text{C}$	Cool ing rate $^{\circ}$ C/s	Surfac e temper ature of steel after control led cooling / $^{\circ}\text{C}$
Example 1	8.1	1180	455	175	1210	26	942	917	43	454
Example 2	7.5	1100	458	138	1230	18	908	905	36	448
Comparative Example 1 (C+Mn not satisfied)	7.4	1090	460	165	1220	22	925	910	38	450
Comparative Example 2	7.4	1090	460	165	1220	22	925	910	38	450

(Nb+V not satisfied)										
Comparative Example 3 (Insufficient stack cooling duration)	4.5	1090	715	165	1220	22	925	910	38	450
Comparative Example 4 (Insufficient heating duration)	7.4	1090	460	110	1220	22	925	910	38	450
Comparative Example 5 (Excessively long heating duration)	7.4	1090	460	200	1220	22	925	910	38	450
Comparative Example 6 (Insufficient furnace temperature)	7.4	1090	460	165	1180	22	925	910	38	450
Comparative Example 7 (Excessively high furnace temperature)	7.4	1090	460	165	1280	22	925	910	38	450
Comparative Example 8 (No flange cooling in universal rolling)	7.4	1090	460	165	1220	/	925	930	38	470
Comparative Example 9 (High temperature-controlled rolling temperature in universal rolling)	7.4	1090	460	165	1220	22	1050	960	38	510

Comparative Example 10 (Low cooling rate in post-rolling controlled cooling of universal rolling)	7.4	1090	460	165	1220	22	925	910	20	500
Comparative Example 11 (High cooling rate in post-rolling controlled cooling of universal rolling)	7.4	1090	460	165	1220	22	925	910	60	320

[0057] The performance of the H-section steel produced according to the above method is shown in Table 3. Sampling and sample preparation were carried out according to GB/T 2975, the tensile test was performed in accordance with GB/T 228.1, and the impact test was performed in accordance with GB/T 229.

5 **[0058]** Table 3 Main properties of each Example and Comparative Example

Category	Flange thickness	Yield strength	Tensile strength	Elongation	Impact		
	/mm	ReH/MPa	Rm/MPa	A%	KV ₂ /J		
Example 1	140	466	613	26.5	96	87	106
Example 2	62.7	493	680	22.0	105	92	78
Comparative Example 1 (C+Mn not satisfied)	140	449	602	24.5	83	89	101
Comparative Example 2 (Nb+V not satisfied)	140	431	610	23.5	66	90	95
Comparative Example 3 (Insufficient stack cooling duration)	140	472	641	20.0	93	78	93
Comparative Example 4 (Insufficient heating duration)	140	452	623	22.5	38	67	67
Comparative Example 5 (Excessively long heating duration)	140	441	645	21.0	28	54	41

Comparative Example 6 (Insufficient furnace temperature)	140	438	594	23.0	52	39	33
Comparative Example 7 (Excessively high furnace temperature)	140	435	588	20.0	38	22	45
Comparative Example 8 (No flange cooling in universal rolling)	140	410	568	21.0	52	47	35
Comparative Example 9 (High temperature-controlled rolling temperature in universal rolling)	140	448	582	22.0	28	39	38
Comparative Example 10 (Low cooling rate in post-rolling controlled cooling of universal rolling)	140	398	565	23.0	42	55	71
Comparative Example 11 (High cooling rate in post-rolling controlled cooling of universal rolling)	140	502	730	22.0	47	96	75

[0059] The underlined data above are the data that do not meet the requirements of the present application.

[0060] When producing the hot-rolled H-section steel with a flange thickness of 60mm to 140mm by the method involved in the present disclosure, the product has a yield strength ReH of 466MPa to 493MPa, a tensile strength of 613MPa to 680MPa, an elongation of 22.0% of 26.5%, and an impact value at -20°C of 78J to 106J, as shown in Table 1 in detail. The metallographic structure of the product is shown in FIG. 2, which shows that its surface layer is tempered sorbite; the core is ferrite + pearlite, the grain size is 8.0 grade, and there are no white spots on the fracture of the tensile sample, as shown in (a) in FIG. 3. The hot-rolled H-section steel with the flange thickness of 140mm produced without the method and device involved in the present application has a yield strength ReH of 398MPa to 502MPa, a tensile strength of 568MPa to 730MPa, an elongation of 20.0% to 24.5%, and an impact value at -20°C of 22J to 101J, as detailed in Table 1. There are fish-eye white spots on the fracture of the tensile sample of the product, as shown in FIG. 3(b).

CLAIMS

1. A 460MPa-grade extra-thick hot-rolled H-section steel, comprising the following components by mass percentage:

5 C: 0.10% to 0.20%, Si: 0.30% to 0.50%, Mn: 0.8% to 1.50%, P≤0.015%, S≤0.005%, Nb: 0.010% to 0.050%, V: 0.040% to 0.100%, Ti: 0.006% to 0.020%, Cr: 0.10% to 0.30%, N: 0.0060% to 0.0120%, with the balance being Fe and inevitable impurities.

2. The 460MPa-grade extra-thick hot-rolled H-section steel according to claim 1, wherein
10 the components of the 460MPa-grade extra-thick hot-rolled H-section steel satisfy:
 $0.35\% \leq C + Mn/6 \leq 0.45\%$.

3. The 460MPa-grade extra-thick hot-rolled H-section steel according to claim 1 or 2,
wherein the components of the 460MPa-grade extra-thick hot-rolled H-section steel satisfy:
15 $0.060\% \leq Nb + V \leq 0.130\%$.

4. A method for producing the 460MPa-grade extra-thick hot-rolled H-section steel
according to any one of claims 1 to 3, wherein the method comprises stack cooling after casting
and withdrawal of a blank; then heating, and controlled rolling and controlled cooling.

5. The method according to claim 4, wherein for the stack cooling, the stack cooling is
carried out for a duration t_d of > 5 h.

6. The method according to claim 4, wherein the duration t_d of the stack cooling and a
25 temperature T_d of the blank before entering the stack cooling zone satisfy a relational expression:

$$t_d = -10.16 + \left(\frac{62464.91}{2464.65 \times \sqrt{\pi/2}} \times e^{-2((T_d - 1741.20)/2464.25)^2} \right)$$
, and the temperature T_d of the blank before
entering the stack cooling zone is 900°C to 1300°C.

7. The method according to claim 4, wherein for the heating, the blank after stack cooling
30 is sent to a heating furnace for heating, the heating is controlled at a duration of 120min to

180min, the heating furnace is controlled at a temperature of 1200°C to 1250°C; a discharging temperature is 1200°C to 1250°C.

5 8. The method according to claim 4, wherein for the controlled rolling and controlled cooling, a universal rolling stage is carried out after a breakdown rolling stage.

10 9. The method according to claim 8, wherein for the universal rolling stage, a flange cooling device is activated in the 1st to 4th passes to perform controlled cooling on a flange, with a flange cooling rate of 15°C /s to 30°C /s; in the 2nd pass of universal rolling, temperature-controlled rolling is adopted, and a start rolling temperature for a web is controlled at 900°C to 950°C.

15 10. The method according to claim 8 or 9, wherein after the rolling process in the universal rolling stage is completed, post-rolling controlled cooling is carried out through a rapid cooling device, a start cooling temperature is controlled at 900°C to 950°C, a cooling rate is controlled at 30°C/s to 50°C/s, and a surface temperature of the steel after controlled cooling is controlled at 400°C to 500°C.