

(19)



(11)

EP 4 144 459 B1

(12)

EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:

02.10.2024 Bulletin 2024/40

(21) Application number: **21829482.5**

(22) Date of filing: **25.06.2021**

(51) International Patent Classification (IPC):

B22D 11/22 ^(2006.01) **B22D 11/124** ^(2006.01)
B22D 11/128 ^(2006.01) **C21D 1/84** ^(2006.01)
C21D 9/00 ^(2006.01) **C21D 1/60** ^(2006.01)
C21D 1/62 ^(2006.01) **C21D 1/667** ^(2006.01)

(52) Cooperative Patent Classification (CPC):

B22D 11/225; B22D 11/124; B22D 11/1287;
C21D 9/0081; C21D 1/60; C21D 1/62; C21D 1/667;
C21D 2211/005

(86) International application number:

PCT/CN2021/102405

(87) International publication number:

WO 2021/259376 (30.12.2021 Gazette 2021/52)

(54) **METHOD FOR REDUCING SURFACE CRACKS OF CASTING BLANK BY USING FERRITE PHASE**

VERFAHREN ZUR VERMINDERUNG VON OBERFLÄCHENRISSEN BEI GUSSROHLINGEN
UNTER VERWENDUNG EINER FERRITPHASE

PROCÉDÉ DE RÉDUCTION DE FISSURES DE SURFACE D'UNE ÉBAUCHE DE COULÉE À L'AIDE
D'UNE PHASE DE FERRITE

(84) Designated Contracting States:

AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR

(30) Priority: **25.06.2020 CN 202010592850**

(43) Date of publication of application:

08.03.2023 Bulletin 2023/10

(73) Proprietor: **BAOSHAN IRON & STEEL CO., LTD.**
Shanghai 201900 (CN)

(72) Inventors:

- **WANG, Yingchun**
Shanghai 201900 (CN)
- **XU, Guodong**
Shanghai 201900 (CN)

- **XU, Rongjun**
Shanghai 201900 (CN)
- **FAN, Zhengjie**
Shanghai 201900 (CN)
- **RUAN, Xiaoming**
Shanghai 201900 (CN)
- **WANG, Yan**
Shanghai 201900 (CN)

(74) Representative: **FARAGO Patentanwälte GmbH**
Steinsdorfstraße 14
80538 München (DE)

(56) References cited:

CN-A- 101 722 287 CN-A- 102 228 968
CN-A- 102 861 890 CN-A- 104 399 923
CN-A- 110 756 756 JP-A- 2010 082 638
JP-A- 2012 176 436 US-A1- 2018 363 088

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

EP 4 144 459 B1

Description

TECHNICAL FIELD

[0001] The present invention relates to the technical field of continuous casting, and specifically relates to a method for reducing surface cracks of a casting slab by ferrite phase.

BACKGROUND

[0002] In a production process of metallurgical continuous casting, metallurgical workers pay close attention to the internal and external quality of a casting slab. The internal quality problems of the casting slab are mainly manifested in inhomogeneous compositions, looseness, shrinkage cavities, cracks and other defects, while the external quality problems include slag inclusion, cracks and other defects. As these defects will be inherited in subsequently rolled products, casting slabs with excellent internal and external structures are desired.

[0003] The formation of cracks in the casting slab is a result of the combined effect of metallurgical and mechanical factors in the continuous casting process. Whether cracks appear in the casting slab depends on the structure performance of steel, metallurgical behavior of solidification, process parameters of the casting machine and operating status of equipment. Controlling the structure of the casting slab is one of the effective ways to improve the comprehensive properties of the material. In the continuous casting process, the as-cast structure of the casting slab is typically controlled by controlling the supercooling degree of molten steel, electromagnetic stirring, or adding nucleating agent such as aluminum, titanium or a rare earth element. In the continuous casting process, the surface layer structure of the casting slab can also be controlled by changing the cooling rate and the heating process of the casting slab. As the casting slab is still in an austenite single-phase region when leaving the mold, so the cooling intensity of the mold are crucial to the structure of the surface layer. General surface cracks of the casting slab occur in the straightening section of the casting machine where the casting slab is subjected to straitening effect and generates tensile stress on the inner surface of the casting slab, which leads to cracks on the low-plasticity structure of the casting slab under the effect of the tensile stress. Therefore, performing controlled cooling to the casting slab in the casting machine before entering the straitening section can effectively control the structure of the casting slab and improve the mechanical property of the casting slab.

[0004] In Patent CN110653352A, in order to eliminate surface cracks of the casting slab caused by ferrite, a row of cooling water nozzles with small spray angles are added in front of the straightening section and Narrow-area strong cooling is provided to eliminate proeutectoid ferrite on the surface to control surface cracks of the casting slab. In Patent CN107695313A, intensive cooling

quenching is also used to eliminate precipitation of ferrite and carbonitride on the surface layer of the casting slab, so as to avoid embrittlement and improve the plasticity of the casting slab, thereby reducing surface cracks of the casting slab. In Patent CN105478704B, lifting devices of secondary-cooling water spraying frame are established, which can achieve dynamic control of secondary-cooling water cooling area and automatic adjustment of water flow rate. In this way, secondary-cooling water would not cool the corner of the casting slab directly and avoid corner cracks caused by extremely low temperature or temperature change. Patent documents JP 2012 176436 A, CN 102 861 890 A and US 2018/363088 A1 also disclose a method for reducing surface cracks of a casting slab.

[0005] It can be seen from the above patent that there mainly has two technical paths to solve surface cracks of the casting slab. One path is operating under high temperature to increase the surface layer temperature of the casting slab, thereby preventing phase transition and precipitation of ferrite film and carbonitride precipitate at grain boundary. In this way, the continuous casting machine will be kept under high-temperature state and greatly effect on the accuracy and service life of the equipment. The other path is operating under low temperature to avoid the third brittle area of steel. Such method requires a large amount of cooling water, which will greatly affect energy and environment. Therefore, it is necessary to find a structure state that can improve the plasticity of the steel from the steel itself.

SUMMARY

[0006] The present invention aims to provide a method for reducing surface cracks of a casting slab by ferrite phase, which forms high-proportion ferrite structure on the surface layer of the casting slab to reduce surface cracks of the casting slab. The method can not only control the surface layer structure of the casting slab, but also improve the plasticity of the surface layer of the casting slab, and reduce surface cracks of the casting slab.

[0007] The technical solutions of the present invention are disclosed in appended claims 1-8.

[0008] Specifically, in the method for reducing the surface cracks of the casting slab by ferrite phase of the present invention, wherein in production of metallurgical continuous casting, the casting slab is formed by a steel with a carbon content of $0 < C \leq 0.25\%$; controlling the surface layer temperature of the casting slab to keep the temperature within the austenite-to-ferrite transition temperature so that the proportion of the ferrite phase on the surface layer of the casting slab reaches 35% or more before the straightening point of the casting machine.

[0009] In the process of the continuous casting, smelted steel is solidified in a mold to form a solid casting slab having a certain thickness, and at this time, the temperature of the casting slab is 1000-1250°C. Later, the casting slab is cooled and transported by a supporting roller

while cooling. After bending, the casting slab enters the bow section, and is further transported to the straightening point of the casting machine for straightening; then the casting slab passes through a horizontal section of the casting machine for complete solidification and is transported out of the casting machine.

[0010] In the present invention, the control of the surface temperature of the casting slab is carried out before the casting slab reaches the straightening point of the casting machine. At first, the solidified casting slab passing through the mold has a relatively high temperature, which can be cooled by cooling water to keep the surface layer temperature of the casting slab within the austenite-to-ferrite transition temperature. Cooling rate can be determined by a continuous cooling characteristic CCT curve of the steel. The present invention focuses on controlling the surface layer temperature of the casting slab to maintain the temperature within the range of austenite-to-ferrite transition temperature, so as to achieve the transformation from austenite to ferrite. It is found through research that the proportion of the ferrite phase on the surface layer of the casting slab needs to reach 35% or more before the straightening point of the casting machine. After satisfying this condition, the casting slab with the desired phase proportion can enter the straightening point of the casting machine, and straightening the slab into a horizontal casting slab.

[0011] In the present invention, the exact time to cool the casting slab or keep the temperature within the range of the austenite-to-ferrite transition temperature may be adjusted according to production conditions, as long as the proportion of the ferrite phase on the surface layer of the casting slab before the straightening point of the casting machine is 35% or more. The surface layer of the casting slab refers to a portion with a casting slab thickness of 10 mm or less. Controlling the proportion of the ferrite phase on the surface layer of the casting slab to 35% or more, and controlling the surface layer temperature of the casting slab are both performed to the portion with a casting slab thickness of 10 mm or less.

[0012] According to the method for reducing the surface cracks of the casting slab by ferrite phase of the present invention, the range of cooling rate of the casting slab to the ferrite phase is determined by a continuous cooling characteristic CCT curve of the steel. The casting slab is cooled within the range of cooling rate, so that the surface layer temperature of the casting slab is lowered into the range of the austenite-to-ferrite transition temperature and maintained within the above temperature range. Specifically, the surface layer temperature of the casting slab is controlled in an bow section of the casting machine to keep within the range of the austenite-to-ferrite transition temperature.

[0013] The range of cooling rate for the ferrite phase of the steel is 3-0.05°C/s according to the continuous cooling characteristic CCT curve of the steel. Preferably, the cooling rate range is 3-0.1°C/s and more preferably of 1.5-0.08°C/s. The cooling rate can be controlled by

configuring parameters in the program model and is conducive to keeping the temperature of the casting slab in the vicinity of the phase transition temperature of ferrite, so as to facilitate the formation of the ferrite.

5 **[0014]** Preferably, the surface layer temperature of the casting slab is controlled, so that the proportion of the ferrite phase on the surface layer of the casting slab reaches 35%-100%, preferably 35%-75% before the straightening point of the casting machine. The proportion of ferrite enables the surface layer of the casting slab to obtain good plasticity. Furthermore, the time for forming the proportion of the ferrite is easier to satisfy and control.

10 **[0015]** The surface layer of the casting slab is kept within an austenite-to-ferrite transition temperature range of 900°C-600°C and held for 0.44-35 min.

15 **[0016]** According to the method for reducing the surface cracks of the casting slab by ferrite phase, the surface layer temperature of the casting slab is controlled by cooling water. Different from the above-mentioned cooling that reduce temperature, the cooling described herein is a cooling that maintain temperature. In order to distinguish from the above-mentioned cooling that reduce temperature, the cooling that cooled the surface layer temperature of the casting slab to the austenite-to-ferrite transition temperature is referred to as first cooling, and the cooling that maintain the temperature at the austenite-to-ferrite transition temperature is referred to as second cooling. After the surface layer of the casting slab is cooled to a predetermined temperature range, it is also necessary to control the surface layer temperature of the casting slab to be within the predetermined temperature range. In the present invention, the surface layer temperature of the casting slab can be maintained by spraying cooling water (that is, the second cooling mentioned above). This is because the central temperature of the casting slab is relatively high, and if no cooling is carried out, the heat of the center will be transferred to the surface layer of the casting slab and increase the surface layer temperature of the casting slab. Therefore, the surface layer temperature of the casting slab can be controlled by the cooling water.

20 **[0017]** The flow rate of the cooling water required for the surface layer temperature of the casting slab to keep within the range of the austenite-to-ferrite transition temperature is calculated by a continuous casting online model. Specifically, the model is a common model in the art, and the continuous casting online model of the present invention is a continuous casting and secondary cooling online model, whereby the surface temperature of the casting slab is calculated according to the heat transfer principle in combination with continuous casting process conditions, such as molten steel temperature, casting slab casting speed, and cooling water. The model can calculate the flow rate of the cooling water required for different areas of the casting slab according to a target temperature set by the process, so as to control the temperature of the casting slab. During use, only by setting

the temperature that need to be maintained for the surface layer of the casting slab, the flow rate of spraying water can be calculated by the continuous casting and secondary cooling online model, then water is sprayed to cool and control the surface layer temperature of the casting slab within a predetermined range.

[0018] After research, typically, the water spraying flow rate of cooling water for the second cooling can be suitably controlled within a range of 0-0.87 L/kg (including 0 and 0.87), which can control the surface layer temperature of the casting slab within the range of austenite-to-ferrite transition temperature. The unit L/kg of the water spraying flow rate refers to a water spraying volume required by steel in unit mass.

[0019] According to the method for reducing the surface cracks of the casting slab by ferrite phase, preferably, the surface layer of the casting slab is kept at the austenite-to-ferrite transition temperature for a long time by the cooling water, and a secondary cooling nozzle is used to spray water to the surface layer of the casting slab for cooling, so as to control the surface layer temperature of the casting slab. Specifically, for the present invention, uniform cooling can be achieved at a small water volume (0-0.62 L/kg).

[0020] Alternatively, in order to keep the surface layer of the casting slab at the austenite-to-ferrite transition temperature for a long time, sometimes a low first cooling rate is required, therefore non-water spraying cooling can be adopted, that is, keeping at the air cooling state, which is also referred to as dry cooling. Similarly, in order to keep the surface layer temperature of the casting slab within the austenite-to-ferrite transition temperature, dry cooling can also be used if a low second cooling rate is required. Specifically, during application of the continuous casting and secondary cooling online model, when a low second cooling rate is required, the model will reduce the water spraying flowrate to avoid decrease of the surface layer temperature of the casting slab. Moreover, when the temperature drops too fast, the model will use air cooling to keep the surface temperature of the casting slab. When the surface layer temperature of the casting slab is controlled by the air cooling, a relatively high temperature will be easily caused correspondingly due to the fact that there is no cooling water to cool the supporting roller of the bow section of the casting machine. Therefore, it is necessary to cool the supporting roller of the bow section of the casting machine. In the present disclosure, the supporting roller of the bow section of the casting machine is cooled internally. Specifically, cooling water can be fed to the inside of the supporting roller to control the surface temperature of the supporting roller to 550°C or less, so as to prevent a bow section from being damaged. The bow section here may also be referred to as the bow section.

[0021] According to the method of the present invention, cooling water is used to control the surface layer temperature of the casting slab before the straightening section of the casting machine, so that the surface tem-

perature of the casting slab is kept constant in the vicinity of the austenite-to-ferrite transition temperature for a long time. In order to better control the surface layer temperature of the casting slab by cooling water, a secondary cooling nozzle with good atomization effect and uniform spraying is required. A nozzle that can conduct uniform spraying cooling under the condition of a small water volume is especially needed. In some practical cases, dry cooling, that is, no secondary cooling water is sprayed for continuous casting, is required for the casting slab to keep the temperature constant. In this case, the supporting roller of the bow section needs good internal cooling, so as to avoid damages of supporting roller and bearing of the bow section caused by high temperature of the casting slab. In order to control the surface layer temperature of the casting slab at a certain temperature, a continuous casting model is needed to control the surface layer temperature of the casting slab online and in real time. At present, many casting machines have been equipped with a continuous casting online control model. By means of this model, the amount of cooling water required for the surface layer temperature of the casting slab can be configured. By keeping the temperature constant for a long time, a ferrite layer is formed on the surface layer of the casting slab, by which the plasticity of the surface layer structure of the casting slab can be improved because of the high plasticity of ferrite as the proportion of ferrite in the surface layer structure of the casting slab increases, thereby reducing cracks generated at the inner surface of the casting slab due to tensile stress at the straightening section.

[0022] In the continuous casting process, the surface layer temperature of the casting slab after leaving the mold is in high temperature area, generally at 1000-1250°C. The surface layer structure of the casting slab at the moment is in austenite region. The steel has relatively high plasticity at the case of single phase and would not generate cracks. However, as the casting slab is cooled at the bow section by the cooling water, the temperature of the surface layer structure of the casting slab decreases continuously. When the temperature reaches the phase transition temperature, the transformation of the austenite in the casting slab to proeutectoid ferrite belongs to diffusion type phase transition. At a relatively low cooling rate, the proeutectoid ferrite first nucleates at an initial austenite grain boundary and grows along the grain boundary. After continued cooling, the ferrite in the grain starts to nucleate. At the moment, a relatively coarse proeutectoid ferrite film has been formed at the initial austenite grain boundary. When the casting slab passes through the straightening area, the structure is subjected to the straightening tensile stress that will lead to cracks on the ferrite film at the austenite grain boundary, and the cracks gradually spread in the later stage. During straightening of the casting slab, if the proportion of the ferrite in the structure of the casting slab is low, which is less than 35%, the proeutectoid ferrite film easily causes stress concentration to form cracks,

but if the proportion of the ferrite exceeds 35%, the stress concentration will not occur, which can avoid cracks. Thermodynamic and dynamic factors, i.e., temperature and duration, both affect the precipitation proportion of the ferrite. Phase transition temperatures at different cooling rates are obtained according to the continuous cooling characteristic CCT curve of the steel. Generally, the ferrite can be formed in steel within a cooling rate of 3-0.05°C/s and a temperature range of 900°C-600°C. If the surface layer temperature of the casting slab is controlled in the vicinity of the phase transition temperature for a long time, a large amount of ferrite will be formed on the surface layer of the casting slab. The holding time for the present invention is 0.44-35 min. When the proportion of the ferrite exceeds 35%, the plasticity of the structure of the casting slab will be significantly improved, which can avoid cracks. Therefore, after the casting slab passes through a bending section, that is, the bow section, weak cooling is performed in a cooling manner with a cooling rate of less than 3°C/s to keep the surface layer temperature of the casting slab constant within the range of austenite-to-ferrite transition temperature, and maintain the temperature until the straightening section. In this way, a high-proportion ferrite layer is formed on the surface layer of the casting slab instead of a low-proportion ferrite film on the austenite grain boundary only. Casting slab having high-proportion ferrite layer will not be confronted to cracks caused by stress concentration when passing through the straightening section. One innovation of the present invention is that the method keeps the surface temperature of the casting slab constant in the vicinity of the austenite-to-ferrite transition temperature for a long time. There are two key points: one is keeping the temperature for a long time, and the other is controlling the temperature in the vicinity of the phase transition temperature.

[0023] The present invention has the following beneficial technical effects:

The method of the present invention controls the surface layer temperature of the casting slab in the bow section of the casting machine, so that the surface layer temperature of the casting slab is constant in the vicinity of the phase transition temperature of the steel for a long time, and a large number of ferrite phases can be formed on the surface of the casting slab through the process. When the casting slab with the high-proportion ferrite phase passes through the straightening section of the casting machine, since there are a large number of ferrite phases in the structure, the tensile stress of the inner surface of the casting slab will not be concentrated at the grain boundary, and will not tear the grain boundary, thus avoiding the surface cracks of the casting slab. This technology is very helpful to improve the surface plasticity of the casting slab, while reducing the surface cracks of the casting slab and improving the surface quality of a product.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024]

Fig. 1A is a schematic diagram showing the micro-structure on the surface layer of a casting slab of Comparative example 1;

Fig. 1B is a schematic diagram showing the micro-structure on the surface layer of a casting slab of Embodiment 3; and

Fig. 2 is a continuous casting cooling characteristic CCT curve of steel in Embodiment 1.

DETAILED DESCRIPTION

[0025] The present invention is further described below in combination with the embodiments. Those skilled in the art should understand that the embodiments are only for example, and are not intended to constitute any limitation to the present invention as defined in the appended set of claims.

[0026] The implementation process of the method of the present invention is described in detail below:

First, a continuous cooling characteristic CCT curve of steel is tested or calculated to obtain a range of the first cooling rate of the steel that forms ferrite, which is 3-0.05°C/s, and austenite-to-ferrite transition temperature at a different cooling rate, which is 900°C-600°C. After cooling, the temperature is kept at 900°C-600°C for 0.44-35 min, and the process is completed before the straightening point.

[0027] As shown in Fig. 2, a CCT curve of steel in Embodiment 1 below shows the relationship between the evolution of steel structure, the temperature and the time at several cooling rates. The austenite-to-ferrite transition temperature at a certain cooling rate, and the time for forming a certain proportion of ferrite can be obtained from the figure. In Fig. 2, the X-axis in the figure represents the cooling time, and the Y-axis represents the temperature, while multiple curves similar to a parabola in the figure represent the cooling rates. The area marked with F in the figure is the area where ferrite is formed; the area marked with P in the figure represents pearlite; and the area marked with B in the figure represents bainite. It can be seen that the cooling rates contained in area F is the range of cooling rate that can form ferrite. According to the CCT curve in Fig. 2, the austenite-to-ferrite transition temperature can also be obtained, which is 560-620°C. As for the holding time of the austenite-to-ferrite transition temperature in Embodiment 1, it is obtained in the present invention according to research determination that a holding time of 0.44-35 min can ensure the proportion of the ferrite phase on the surface of the casting slab to reach 35% or more.

[0028] Embodiment 1: Steel 1 includes 0.08% of C, 0.14% of Si, 1.69% of Mn, 0.41% of Cr, 0.02% of Mo, and the balance of iron and inevitable impurities. According to continuous cooling characteristics, the cooling rate

range where ferrite can be formed is less than 0.1°C/s . The present embodiment adopts 0.1°C/s as the cooling rate. At this cooling rate, the austenite-to-ferrite transition temperature is 620°C and the holding time is 11.67 min, so that a ferrite proportion of more than 35% can be formed on the surface layer of the casting slab. This process is completed before the straightening point. After the production, it can be determined that more than 35% of ferrite is formed by observing the casting slab specimen through metallographic microscope and calculation.

[0029] Embodiment 2: Steel 2 includes 0.16% of C, 0.07% of Si, 1.04% of Mn, 0.88% of Cr, 0.02% of Ti, and the balance of iron and inevitable impurities. According to continuous cooling characteristics, the cooling rate range where ferrite can be formed is $0.1\text{--}3^{\circ}\text{C/s}$, wherein the austenite-to-ferrite transition temperature is 750°C at a cooling rate of 0.1°C/s , and 630°C at a cooling rate of 3°C/s . In Embodiment 2, cooling is carried out at a cooling rate of 0.2°C/s , then the surface layer temperature of the casting slab is kept at 720°C for 10 min. This process is completed before the straightening point. After the production, it can be determined that more than 35% of ferrite is formed by observing the casting slab specimen through metallographic microscope and calculation.

[0030] Embodiment 3: Steel 3 includes 0.077% of C, 0.09% of Si, 1.45% of Mn, 0.03% of Cr, 0.01% of Mo, and the balance of iron and inevitable impurities. According to continuous cooling characteristics, the cooling rate range where ferrite can be formed is $0.1\text{--}3^{\circ}\text{C/s}$. The austenite-to-ferrite transition temperature is 790°C at a cooling rate of 0.1°C/s , and 730°C at a cooling rate of 3°C/s . In Embodiment 3, cooling is carried out at a cooling rate of 0.3°C/s , then the surface layer temperature of a casting slab is kept at 780°C for 7.22 min. This process is completed before the straightening point. After the production, it can be determined that more than 35% of ferrite is formed by observing a casting slab specimen is observed through a metallographic microscope and calculation.

[0031] Embodiment 4: Steel 4 includes 0.09% of C, 0.17% of Si, 0.83% of Mn, 0.02% of Cr, and the balance of iron and inevitable impurities. According to continuous cooling characteristics, the cooling rate range where ferrite can be formed is $0.1\text{--}3^{\circ}\text{C/s}$. The austenite-to-ferrite transition temperature is 830°C at a cooling rate of 0.1°C/s , and 780°C at a cooling rate of 3°C/s . In Embodiment 4, cooling is carried out at a cooling rate of 0.5°C/s , then the surface layer temperature of a casting slab is kept at 820°C for 5.67 min. This process is completed before the straightening point. After the production, it can be determined that more than 35% of ferrite is formed by observing a casting slab specimen and calculation.

[0032] Comparative example 1: Steel in Comparative example 1 includes 0.077% of C, 0.09% of Si, 1.45% of Mn, 0.03% of Cr, 0.01% of Mo, and the balance of iron and inevitable impurities. Casting is performed by a conventional process. After leaving the mold, the casting slab is cooled. The surface temperature of the casting slab at

an outlet of the mold is 1200°C . The surface temperature of the casting slab gradually decreases by secondary cooling water in the bow section and reaches to 750°C when the casting slab enters the straightening point. At the moment, in the structure of the surface of the casting slab, ferrite is precipitated at the austenite grain boundary, as shown in Fig. 1A. Tensile stress is generated on the surface of the casting slab due to straightening, forming cracks at the position where the ferrite is precipitated in the austenite grain boundary.

[0033] The above only lists combinations of cooling rates, phase transition temperatures and time for four steel grades, which do not exclude combinations of other process parameters of other kinds of steel.

[0034] Fig. 1A and Fig. 1B show cooled casting slabs after the casting slabs of the steel in Comparative example 1 and Embodiment 3 pass through the straightening point, then the percentages of the microstructures of the surfaces of the casting slabs are measured. It can be seen from the figures that the microstructure of the surface of the casting slab in Comparative example 1 is mainly austenite, and the content of ferrite is only 8%. Therefore, stress concentration is easily caused at the ferrite and forms cracks under the action of external force. In Embodiment 3, the casting slab is kept at 780°C at the cooling rate of 0.3°C/s and holding for 7.22 min. 95% of ferrite will be formed on the surface of the casting slab when the casting slab enters the straightening point. Stress concentration will not occur in such structure under external force, and the ferrite has good plasticity, so that no cracks are formed.

[0035] Of course, those of ordinary skill in the art should recognize that the above embodiments are only used to illustrate the present invention, but not to limit the present invention. Changes and transformations made to the above embodiments shall all fall within the scope of the claims of the present invention.

Claims

1. A method for reducing surface cracks of a casting slab by ferrite phase, wherein in production of metallurgical continuous casting, a surface layer temperature of a casting slab is controlled to keep at an austenite-to-ferrite transition temperature range of $900^{\circ}\text{C}\text{--}600^{\circ}\text{C}$ for 0.44-35 min, thereby obtaining a high-proportion ferrite phase so that the proportion of the ferrite phase on a surface layer of the casting slab reaches 35% or more before a straightening point of a casting machine; wherein the surface layer temperature of the casting slab is controlled in a bow section of the casting machine and a second cooling rate of the ferrite phase of the steel determined by a continuous cooling characteristic CCT curve of steel is controlled to $3\text{--}0.05^{\circ}\text{C/s}$.
2. The method for reducing the surface cracks of the

casting slab by ferrite phase according to claim 1, wherein the casting slab is formed by a steel with a carbon content of $0 < C \leq 0.25\%$; controlling the surface layer temperature of the casting slab to keep the temperature within a range of the austenite-to-ferrite transition temperature so that the proportion of the ferrite phase on the surface layer of the casting slab reaches 35% or more before the straightening point of the casting machine, then the casting slab enters the straightening point of the casting machine.

3. The method for reducing the surface cracks of the casting slab by ferrite phase according to claim 1, wherein a range of cooling rate for transforming the casting slab of the steel to the ferrite phase is determined according to a continuous cooling characteristic CCT curve of the steel; cooling the casting slab within the cooling rate range, so that the surface layer temperature of the casting slab is lowered into the range of the austenite-to-ferrite transition temperature; then the surface layer temperature of the casting slab is controlled in an bow section of the casting machine.
4. The method for reducing the surface cracks of the casting slab by ferrite phase according to claim 1, wherein the surface layer temperature of the casting slab is controlled in a bow section of the casting machine; and a second cooling rate of the ferrite phase of the steel determined by a continuous cooling characteristic CCT curve of steel is controlled to $3-0.1^\circ\text{C/s}$.
5. The method for reducing the surface cracks of the casting slab by ferrite phase according to claim 1, wherein the surface layer temperature of the casting slab is controlled, so that the proportion of the ferrite phase on the surface layer of the casting slab reaches 35%-75% before the straightening point of the casting machine.
6. The method for reducing the surface cracks of the casting slab by ferrite phase according to any one of claims 1 to 5, wherein the surface layer temperature of the casting slab is controlled by cooling water; the amount of the cooling water required for the surface layer temperature of the casting slab is calculated by a continuous casting online model.
7. The method for reducing the surface cracks of the casting slab by ferrite phase according to claim 6, wherein the surface layer of the casting slab is kept at the austenite-to-ferrite transition temperature for 0.44-35 min; and a secondary cooling nozzle with good spraying property is used to achieve uniform cooling at small water flow rate.
8. The method for reducing the surface cracks of the

casting slab by ferrite phase according to any one of claims 1 to 5, wherein the surface layer of the casting slab is kept at the austenite-to-ferrite transition temperature for 0.44-35 min by non-water spraying cooling; a supporting roller of a bow section of the casting machine is cooled internally to control a surface temperature of the supporting roller at 550°C or less to prevent damage of the bow section.

Patentansprüche

1. Verfahren zum Reduzieren von Oberflächenrissen einer Gussbramme durch eine Ferritphase, wobei bei der Produktion eines metallurgischen Stranggusses eine Oberflächenschichttemperatur einer Gussbramme so gesteuert wird, dass sie 0,44 - 35 Minuten lang in einem Austenit-Ferrit-Übergangstemperaturbereich von 900°C bis 600°C gehalten wird, wodurch ein hoher Ferritphasenanteil erhalten wird, dergestalt, dass der Anteil der Ferritphase auf einer Oberflächenschicht der Gussbramme vor einem Begradigungspunkt einer Gießmaschine mindestens 35 % erreicht, wobei die Oberflächenschichttemperatur der Gussbramme in einem Bogenabschnitt der Gießmaschine gesteuert wird und eine zweite Abkühlungsrate der Ferritphase des Stahls, die durch eine kontinuierliche Abkühlungskennkurve (Continuous Cooling Characteristic, CCT-Kurve) von Stahl bestimmt wird, auf $3 - 0,05^\circ\text{C/s}$ gesteuert wird.
2. Verfahren zum Reduzieren der Oberflächenrisse der Gussbramme durch eine Ferritphase nach Anspruch 1, wobei die Gussbramme aus einem Stahl mit einem Kohlenstoffgehalt von $0 < C \leq 0,25\%$ gebildet wird, wobei die Oberflächenschichttemperatur der Gussbramme so gesteuert wird, dass die Temperatur innerhalb eines Bereichs der Austenit-Ferrit-Übergangstemperatur gehalten wird, dergestalt, dass der Anteil der Ferritphase auf der Oberflächenschicht der Gussbramme vor dem Begradigungspunkt der Gießmaschine mindestens 35 % erreicht und die Gussbramme dann in den Begradigungspunkt der Gießmaschine eintritt.
3. Verfahren zum Reduzieren der Oberflächenrisse der Gussbramme durch eine Ferritphase nach Anspruch 1, wobei ein Bereich der Abkühlungsrate zum Umwandeln der Gussbramme aus dem Stahl in die Ferritphase gemäß einer kontinuierlichen Abkühlungskennkurve (CCT-Kurve) des Stahls bestimmt wird, wobei die Gussbramme innerhalb des Abkühlungsratenbereichs so abgekühlt wird, dass die Oberflächenschichttemperatur der Gussbramme in den Bereich der Austenit-Ferrit-Übergangstemperatur hinein gesenkt wird und die Oberflächenschichttemperatur der Gussbramme dann in einem Bogenabschnitt der Gießmaschine gesteuert wird.

4. Verfahren zum Reduzieren der Oberflächenrisse der Gussbramme durch eine Ferritphase nach Anspruch 1, wobei die Oberflächenschichttemperatur der Gussbramme in einem Bogenabschnitt der Gießmaschine gesteuert wird und eine zweite Abkühlungsrate der Ferritphase des Stahls, die durch eine kontinuierliche Abkühlungskennkurve (CCT-Kurve) des Stahls bestimmt wird, auf $3 - 0,1 \text{ } ^\circ\text{C/s}$ gesteuert wird. 5
5. Verfahren zum Reduzieren der Oberflächenrisse der Gussbramme durch eine Ferritphase nach Anspruch 1, wobei die Oberflächenschichttemperatur der Gussbramme so gesteuert wird, dass der Anteil der Ferritphase auf der Oberflächenschicht der Gussbramme vor dem Begradigungspunkt der Gießmaschine 35 % - 75 % erreicht. 10
6. Verfahren zum Reduzieren der Oberflächenrisse der Gussbramme durch eine Ferritphase nach einem der Ansprüche 1 bis 5, wobei die Oberflächenschichttemperatur der Gussbramme durch Kühlwasser gesteuert wird, wobei die für die Oberflächenschichttemperatur der Gussbramme erforderliche Kühlwassermenge durch ein Strangguss-Online-Modell berechnet wird. 15
7. Verfahren zum Reduzieren der Oberflächenrisse der Gussbramme durch eine Ferritphase nach Anspruch 6, wobei die Oberflächenschicht der Gussbramme 0,44 - 35 Minuten lang auf der Austenit-Ferrit-Übergangstemperatur gehalten wird und eine Sekundärkühlungsdüse mit gutem Sprühverhalten verwendet wird, um eine gleichmäßige Kühlung bei geringer Wasserströmungsrate zu erreichen. 20
8. Verfahren zum Reduzieren der Oberflächenrisse der Gussbramme durch eine Ferritphase nach einem der Ansprüche 1 bis 5, wobei die Oberflächenschicht der Gussbramme 0,44 - 35 Minuten lang ohne Wassersprühkühlung auf der Austenit-Ferrit-Übergangstemperatur gehalten wird, wobei eine Stützrolle eines Bogenabschnitts der Gießmaschine intern gekühlt wird, um eine Oberflächentemperatur der Stützrolle auf maximal $550 \text{ } ^\circ\text{C}$ zu steuern, um eine Beschädigung des Bogenabschnitts zu verhindern. 25

Revendications

1. Procédé de réduction des fissures de surface d'une plaque de coulée par une phase de ferrite, dans lequel, dans la production d'une coulée métallurgique continue, une température de couche de surface d'une plaque de coulée est contrôlée pour être maintenue dans une plage de températures de transition austénite-ferrite comprise entre $900 \text{ } ^\circ\text{C}$ et $600 \text{ } ^\circ\text{C}$ pendant 0,44 à 35 min, pour obtenir alors une phase à proportion élevée de ferrite, si bien que la propor- 50

tion de la phase de ferrite sur une couche de surface de la plaque de coulée atteint 35 % ou plus avant un point de redressage d'une machine de coulée ; dans lequel la température de la couche de surface de la plaque de coulée est contrôlée dans une section avant de la machine de coulée, et une seconde vitesse de refroidissement de la phase de ferrite de l'acier déterminée par une courbe de transformation par refroidissement continu de l'acier est contrôlée pour être comprise entre 3 et $0,05 \text{ } ^\circ\text{C/s}$.

2. Procédé de réduction des fissures de surface d'une plaque de coulée par une phase de ferrite selon la revendication 1, dans lequel la plaque de coulée est formée par un acier présentant une teneur en carbone de $0 < C \leq 0,25 \%$; en contrôlant la température de la couche de surface de la plaque de coulée pour maintenir la température au sein d'une plage de températures de transition austénite-ferrite telle que la proportion de la phase de ferrite sur la couche de surface de la plaque de coulée atteint 35 % ou plus avant le point de redressage de la machine de coulée, puis la plaque de coulée entre dans le point de redressage de la machine de coulée.
3. Procédé de réduction des fissures de surface d'une plaque de coulée par une phase de ferrite selon la revendication 1, dans lequel une plage de vitesses de refroidissement permettant de transformer la plaque de coulée de l'acier vers la phase de ferrite est déterminée conformément à une courbe caractéristique de transformation par refroidissement continu de l'acier ; le refroidissement de la plaque de coulée au sein de la plage de vitesses de refroidissement de façon telle que la température de la couche de surface de la plaque de coulée est abaissée dans la plage de températures de transition austénite-ferrite ; puis la température de la couche de surface de la plaque de coulée est contrôlée dans une section avant de la machine de coulée.
4. Procédé de réduction des fissures de surface d'une plaque de coulée par une phase de ferrite selon la revendication 1, dans lequel la température de la couche de surface de la plaque de coulée est contrôlée dans une section avant de la machine de coulée ; et une seconde vitesse de refroidissement de la phase de ferrite de l'acier déterminée par une courbe de transformation par refroidissement continu de l'acier est contrôlée entre 3 et $0,1 \text{ } ^\circ\text{C/s}$.
5. Procédé de réduction des fissures de surface d'une plaque de coulée par une phase de ferrite selon la revendication 1, dans lequel la température de la couche de surface de la plaque de coulée est contrôlée de façon telle que la proportion de la phase de ferrite sur la couche de surface de la plaque de coulée atteint 35 % à 75 % avant le point de redres- 55

sage de la machine de coulée.

6. Procédé de réduction des fissures de surface d'une plaque de coulée par une phase de ferrite selon l'une quelconque des revendications 1 à 5, dans lequel la température de la couche de surface de la plaque de coulée est contrôlée par l'eau de refroidissement ; la quantité de l'eau de refroidissement nécessaire pour la température de la couche de surface de la plaque de coulée est calculée par un modèle en ligne de coulée continue. 5 10
7. Procédé de réduction des fissures de surface d'une plaque de coulée par une phase de ferrite selon la revendication 6, dans lequel la couche de surface de la plaque de coulée est maintenue à la température de transition austénite-ferrite pendant 0,44 à 35 min ; et une buse de refroidissement secondaire présentant une bonne propriété de pulvérisation est utilisée pour obtenir un refroidissement uniforme avec un faible débit d'eau. 15 20
8. Procédé de réduction des fissures de surface d'une plaque de coulée par une phase de ferrite selon l'une quelconque des revendications 1 à 5, dans lequel la couche de surface de la plaque de coulée est maintenue à la température de transition austénite-ferrite pendant 0,44 à 35 min par un refroidissement par pulvérisation sans eau ; un rouleau de soutien d'une section avant de la machine de coulée est refroidi en interne pour contrôler une température de surface du rouleau de soutien à 550 °C ou moins afin d'éviter tout endommagement de la section avant. 25 30

35

40

45

50

55

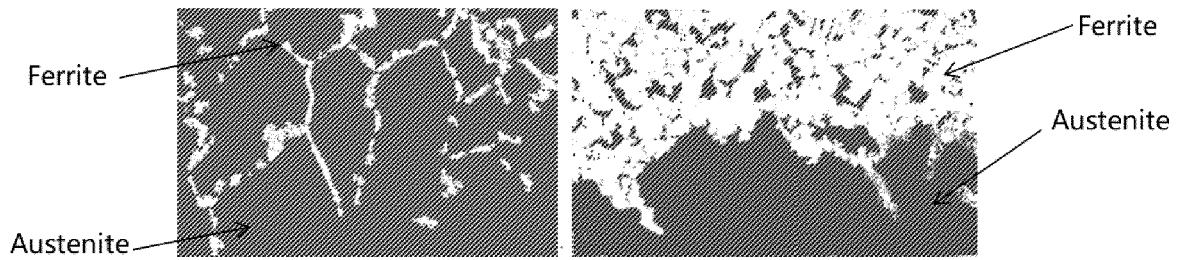


Fig. 1A

Fig. 1B

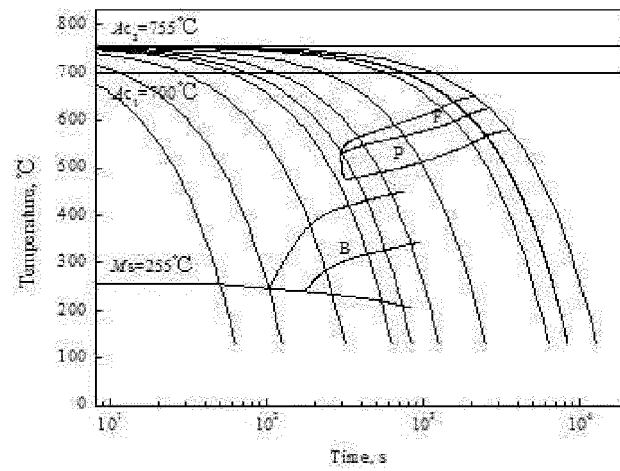


Fig. 2

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- CN 110653352 A [0004]
- CN 107695313 A [0004]
- CN 105478704 B [0004]
- JP 2012176436 A [0004]
- CN 102861890 A [0004]
- US 2018363088 A1 [0004]