

Testing method for Morphology and Position of Solidification Front in Casting Process of Aluminum Alloy

The present application is based upon and claims priority to Chinese patent application No. 2023118341090, filed on December 28, 2023, the disclosure of which is hereby incorporated by reference in its entirety.

Technical Field

The present disclosure relates to the technical field of aluminum alloy casting, and in particular, to testing method for morphology and position of solidification front in casting process of aluminum alloy.

Background

At present, aluminum alloy flat ingots and round ingots for extrusion and rolling deformation are mostly produced by direct water-cooled semi-continuous casting. The main feature of this process is that a liquid metal melt passes through a crystallizer continuously, and solidification and constrained forming of the metal are achieved by means of the crystallizer. In the production process of this process, a liquid metal area on an upper part of the ingot surrounded by a crystallization front and an exposed liquid surface of the ingot is referred to as liquid cavities (i.e., the solidification front). The shape of the liquid cavities of the ingot determines the changes in the metal crystallization speed of the cross section of the ingot, and the depth of the liquid cavities directly reflects the solidification time and solidification speed in the ingot preparation process. Therefore, accurately measuring and adjusting the morphology and position of the solidification front in the casting process is an important indicator and means to reflect and control the quality of the ingot.

The commonly used method for measuring the morphology and position of the solidification front is a point insertion method, that is, in the casting process, a thin wire or probe is inserted vertically from the metal liquid surface into the melt until a solid phase is touched, and then is drawn out. The position of the solidification front in the casting process is measured by measuring the length of the inserted wire or probe at different positions. Although this method is simple and feasible, the measuring accuracy is affected by the experience of an operator and the perpendicularity of the probe, which results in a relatively large error and incapability of accurately reflecting the changes in the position of the solidification front. If the casting condition or process changes, an error value is relatively larger. In order to compensate for the error caused by the wire insertion method, a

thermocouple method came into being. According to the method, in the casting process, metal thermocouples are embedded in different positions inside the ingot online, the thermocouples are solidified with the ingot, and the morphology and position of the solidification front in the casting process are reflected by means of the changes in the temperature of the thermocouples at different positions. This method measures a value of the liquid cavities accurately and can quantitatively reflect the changes in the morphology and position thereof. However, the operation of the metal thermocouple method is complicated, and the ingot can only be scrapped after the measurement is completed, which is costly. When measuring high-strength 7xxx and 2xxx hard aluminum alloy ingots, the embedded thermocouple increases stress concentration points inside the ingot, which may cause the ingot to crack or even burst, and the application field is limited to a certain extent.

Summary

A main objective of the present disclosure is to provide testing method for morphology and position of solidification front in casting process of aluminum alloy, so as to solve the problems of large error and high cost of the method for measuring the morphology and position of the solidification front in the related art.

In order to achieve the above objective, according to one aspect of the present disclosure, a testing method for morphology and position of solidification front in casting process of aluminum alloy is provided. The testing method includes: performing preheating treatment on a grain refiner to obtain a preheated grain refiner; and at a moment A of the casting process, mixing the preheated grain refiner with an aluminum alloy melt flowing through a flow channel, and continuously injecting a mixture into a casting mold for solidification and forming to obtain an aluminum alloy ingot. The maximum height from the aluminum alloy ingot corresponding to the moment of A to the bottom of the casting mold in the casting mold is recorded as H, and a center point of the cross section of the casting mold at the height H is recorded as a center point O. After passing through the center point O and sequentially performing longitudinal sectioning, polishing, and corrosion on a part of the aluminum alloy ingot in a casting direction, the morphology and position of the solidification front at the moment A of the casting process may be revealed, the maximum height of the longitudinally sectioned part of the aluminum alloy ingot from the bottom of the casting mold is recorded as L, the diameter of the cross section of the casting mold in a direction perpendicular to the casting direction is recorded as ϕ , the length of the

longitudinally sectioned part of the aluminum alloy ingot is $H'=L-H$, and H' is 0.1ϕ to 2ϕ .

Further, the mass of the preheated grain refiner and the diameter ϕ of the cross section of the casting mold satisfy the following relationship: the mass of the preheated grain refiner is equal to $10^{-3} \times (0.5-2.5) \rho \pi v_{\text{cast}} (t_B - t_A) \phi^2$, where ρ represents the density of the aluminum alloy melt, t_A represents the time of the moment A, the time after the moment A is a moment B, the time of the moment B is represented by t_B , and v_{cast} represents a casting speed in the casting mold.

Further, a mass ratio of the preheated grain refiner to the aluminum alloy melt flowing through the flow channel is 2: 1 kg/t to 10: 1 kg/t.

Further, in the casting process, the casting process after the casting speed is a fixed value is a stable stage, the preheated grain refiner is respectively added at different moments in the stable stage, and the morphology and position of the solidification front at different moments in the stable stage are measured. The thickness H' of the longitudinally sectioned part of the aluminum alloy ingot is 1ϕ to 2ϕ , and/or the depth of the solidification front in the stable stage is 0.5ϕ to 1.5ϕ .

Further, in the casting process, the casting process before the casting speed is a fixed value is an initial stage, the preheated grain refiner is respectively added at different moments in the initial stage, and the morphology and position of the solidification front at different moments in the initial stage are measured. The thickness H' of the longitudinally sectioned part of the aluminum alloy ingot is 0.1ϕ to 1ϕ , and/or the depth of the solidification front in the initial stage is 0 to 1ϕ .

Further, the temperature of the preheating treatment is 350 °C to 450 °C.

Further, the model of the aluminum alloy is 7050 or 2024.

Further, the casting process of the aluminum alloy includes: sequentially performing smelting, refining, degassing and standing treatment on the aluminum raw ingot to obtain the aluminum alloy melt; and performing semi-continuous casting on the aluminum alloy melt to obtain the aluminum alloy ingot. The semi-continuous casting process includes a continuous initial stage and a continuous stable stage which are sequentially performed. The temperature of the aluminum alloy melt is 720 °C to 740 °C, and/or the casting speed in the continuous initial stage is 30 mm/min to 60 mm/min, and after the casting speed increases linearly to 100 mm/min to 125 mm/min within 1 min to 3 min, the continuous initial stage ends and the continuous stable stage begins.

Further, cooling water is used to cool in the semi-continuous casting process, a flow rate of the cooling water is 4 m³/h to 6 m³/h, and the temperature of the cooling water is 20 °C to 28 °C.

Further, the grain refiner is a rod-shaped grain refiner, the rod-shaped grain refiner is selected from any one or more of Al-5Ti-B, Al-3Ti-B, Al-3Ti-0.15C, and/or the length of the rod-shaped grain refiner is 10 cm to 20 cm.

By applying the technical solution of the present disclosure, compared with the conventional testing method for the morphology and position of the solidification front, the testing method of the present disclosure is mainly as follows: after the longitudinally sectioned part of the aluminum alloy ingot is polished and corroded in a manner of excessively adding the grain refiners (the conventional amount of grain refiners required in the field is added in the aluminum alloy melt) in the casting process by using the differences between the enhanced refining effect and the refining effect of the grain refiner, the morphology and position of the solidification front in the casting process are clearly displayed by using the difference in the grain size. After adopting the testing method of the present disclosure, human errors caused by measuring the depth of the solidification front through a conventional insertion method may be avoided. In the present disclosure, the morphology and position of the solidification front are displayed more intuitively, and the accuracy of measuring results is significantly improved, so that the metal crystallization speed of the cross section of the aluminum alloy ingot, and the solidification moment and solidification speed of the solidification front in the solidification process of the aluminum alloy melt can be more accurately reflected, so as to adjust the solidification time and solidification speed in the solidification process of the aluminum alloy melt according to the measuring results, which helps to improve the quality of the aluminum alloy ingot. In addition, the above testing method is easy to operate and easy to implement, which greatly reduces the cost.

Brief Description of the Drawings

The drawings of the specification, which constitute a part of the present disclosure, are intended to provide a further understanding of the present disclosure, and the exemplary embodiments of the present disclosure and the description thereof are intended to explain the present disclosure and do not constitute an undue limitation on the present disclosure. In the drawings:

Fig. 1 shows a schematic diagram of a measuring flow for morphology and position of

a solidification front in a casting process of an aluminum alloy according to Embodiment 1 of the present disclosure.

Fig. 2 shows a schematic diagram of morphology and position of a solidification front in a casting process (continuous stable stage) of a 7050 aluminum alloy according to Embodiment 1 of the present disclosure.

Fig. 3 shows a schematic diagram of measuring a depth of a solidification front by using a thermocouple method according to Comparative Embodiment 2 of the present disclosure.

Herein, the above drawings include the following reference signs.

1. Aluminum alloy melt 1; 2. grain refiner; 3. aluminum alloy ingot; 4. solidification front; 5. Flow channel.

Detailed Description of the Embodiments

It is to be noted that the embodiments in the present disclosure and features in the embodiments may be combined with each other without conflict. The present disclosure is described below with reference to the drawings and in conjunction with the embodiments in detail.

As analyzed in the background of the present disclosure, the shape of a solidification front determines the changes in the metal crystallization speed of the cross section of an aluminum alloy ingot, and the depth of the solidification front directly reflects the solidification time and solidification speed in the ingot preparation process of the solidification front. Therefore, accurately measuring and adjusting morphology and position of the solidification front in the casting process of an aluminum alloy is an important indicator and means to reflect and control the quality of the aluminum alloy ingot. However, a method for measuring the morphology and position of the solidification front in the related art has the problems of large error and high cost. In order to achieve the above problems, the present disclosure provides testing method for morphology and position of solidification front in casting process of aluminum alloy.

In a typical implementation of the present disclosure, testing method for morphology and position of solidification front in casting process of aluminum alloy is provided. The testing method includes: performing preheating treatment on a grain refiner to obtain a preheated grain refiner; and at the moment A of the casting process, mixing the preheated

grain refiner with an aluminum alloy melt flowing through a flow channel, and continuously injecting a mixture into a casting mold for solidification and forming to obtain an aluminum alloy ingot. The maximum height of the aluminum alloy ingot in the casting mold corresponding to the moment A from the bottom of the casting mold is recorded as H, and a center point of the cross section of the casting mold at the height H is recorded as a center point O. After passing through the center point O and sequentially performing longitudinal sectioning, polishing, and corrosion on a part of the aluminum alloy ingot in a casting direction, the morphology and position of the solidification front at the moment A of the casting process may be displayed, the maximum height of the longitudinally sectioned part of the aluminum alloy ingot from the bottom of the casting mold is recorded as L, the diameter of the cross section of the casting mold in a direction perpendicular to the casting direction is recorded as ϕ , the length of the longitudinally sectioned part of the aluminum alloy ingot is $H'=L-H$, and H' is 0.1ϕ to 2ϕ .

Compared with the conventional testing method for the morphology and position of the solidification front, the testing method of the present disclosure is mainly as follows: after the longitudinally sectioned part of the aluminum alloy ingot is polished and corroded in a manner of excessively adding the grain refiners (the conventional amount of grain refiners required in the field is added in the aluminum alloy melt) in the casting process by using the differences between the enhanced refining effect and the refining effect of the grain refiner, the morphology and position of the solidification front in the casting process are clearly displayed by using the difference in the grain size. After adopting the testing method of the present disclosure, human errors caused by measuring the depth of the solidification front through a conventional insertion method may be avoided. In the present disclosure, the morphology and position of the solidification front are displayed more intuitively, and the accuracy of measuring results is significantly improved, so that the metal crystallization speed of the cross section of the aluminum alloy ingot, and the solidification moment and solidification speed of the solidification front in the solidification process of the aluminum alloy melt can be more accurately reflected, so as to adjust the solidification time and solidification speed in the solidification process of the aluminum alloy melt according to the measuring results, which helps to improve the quality of the aluminum alloy ingot. In addition, the above testing method is easy to operate and easy to implement, which greatly reduces the cost.

In addition, the added preheated grain refiner can melt quickly and solidify and form in the casting mold together with an aluminum alloy ingot to be measured. Specifically, the

grain refiner is added from the end of the flow channel 5 and mixed with the aluminum alloy melt flowing in the flow channel 5, and enters the casting mold together with the aluminum alloy melt to solidify. The central longitudinal section of the aluminum alloy ingot is corroded by alkali liquor or acid liquor for observation. The alkali liquor is 20% to 30% NaOH solution, and the acid liquor is 10% to 20% HNO₃ solution.

In one embodiment of the present disclosure, the mass of the preheated grain refiner and the diameter ϕ of the cross section of the casting mold satisfy the following relationship: the mass of the preheated grain refiner is equal to $10^{-3} \times (0.5-2.5) \rho \pi v_{\text{cast}} (t_B - t_A) \phi^2$, where ρ represents the density of the aluminum alloy melt, t_A represents the time of the moment A, the time after the moment A is a moment B, the time of the moment B is represented by t_B , and v_{cast} represents a casting speed in the casting mold.

The amount of grain refiner added is related to the size specification of the aluminum alloy ingot to be measured. The larger the specification of the aluminum alloy ingot, the faster the flow rate of the aluminum alloy melt in the flow channel 5, and the more grain refiners are added. Preferably, the mass of the preheated grain refiner and the diameter ϕ of the cross section of the casting mold satisfy the following relationship, which helps to exert the difference in the enhanced refining of the grain refiner on the aluminum alloy ingots of different sizes, thereby measuring the morphology and positions of the solidification fronts of the aluminum alloy ingots of different sizes.

In one embodiment of the present disclosure, a mass ratio of the preheated grain refiner to the aluminum alloy melt flowing through the flow channel is 2:1 kg/t to 10:1 kg/t.

The grain refiner is added according to the above ratio and along with the flow of the aluminum alloy melt, which is more conducive to exerting the uniformity and stability of difference in the refining of the grain refiner, thereby improving the clarity of the morphology and position of the solidification front.

According to different measuring purposes, the grain refiner may be continuously injected in different stages of the casting process, so as to reflect the changes in the morphology and position of the solidification front in different stages of the casting process, which is specifically as follows.

In one embodiment of the present disclosure, in the casting process, the casting process after the casting speed is a fixed value is a stable stage, the preheated grain refiner is respectively added at different moments in the stable stage, and the morphology

and position of the solidification front at different moments in the stable stage are measured. The thickness H' of the longitudinally sectioned part of the aluminum alloy ingot is 1ϕ to 2ϕ , and/or the depth of the solidification front in the stable stage is 0.5ϕ to 1.5ϕ .

The thickness of the longitudinally sectioned part of the aluminum alloy ingot is controlled to be within the above range, which helps to more completely reflect the changes in the morphology and position of the solidification front at different moments in the stable stage. Preferably, the depth of the solidification front in the stable stage is within the above range, which accurately reflects the starting position of online annealing applied in the casting process, so as to obtain a balance between forming and loosening control in the casting process.

In one embodiment of the present disclosure, in the described casting process, the casting process before the casting speed is a fixed value is an initial stage, the preheated grain refiner is respectively added at different moments in the initial stage, and the morphology and position of the solidification front at different moments in the initial stage are measured. The thickness H' of the longitudinally sectioned part of the aluminum alloy ingot is 0.1ϕ to 1ϕ , and/or the depth of the solidification front in the initial stage is 0 to 1ϕ .

The thickness of the longitudinally sectioned part of the aluminum alloy ingot is controlled to be within the above range, which helps to more completely reflect the changes in the morphology and position of the solidification front at different moments in the initial stage. Preferably, the depth of the solidification front in the initial stage is within the above range, which accurately reflects the starting position of online annealing applied in the casting process, so as to obtain a balance between forming and loosening control in the casting process.

In one embodiment of the present disclosure, the temperature of the preheating treatment is 350°C to 450°C .

The preheating treatment on the grain refiner can ensure that the grain refiner melts quickly when added to the end of the flow channel 5. The grain refiner is preheated to the above temperature by a resistance furnace for heat reservation, which helps to improve the accuracy and efficiency of the above testing method.

In one embodiment of the present disclosure, the model of the aluminum alloy is any one of 7050 or 2024.

Preferably, the aluminum alloy of the above model is more suitable for obtaining the

morphology and position of the solidification front at different moments in the casting process through the above testing method of the present disclosure.

In one embodiment of the present disclosure, the casting process of the aluminum alloy includes: sequentially performing smelting, refining, degassing and standing treatment on the aluminum raw ingot to obtain the aluminum alloy melt; and performing semi-continuous casting on the aluminum alloy melt to obtain the aluminum alloy ingot. The semi-continuous casting process includes a continuous initial stage and a continuous stable stage which are sequentially performed. The temperature of the aluminum alloy melt is 720 °C to 740 °C, and/or the casting speed in the continuous initial stage is 30 mm/min to 60 mm/min, and after the casting speed increases linearly to 100 mm/min to 125 mm/min within 1 min to 3 min, the continuous initial stage ends and the continuous stable stage begins.

The casting process of the aluminum alloy is controlled to be semi-continuous casting, and the casting speed is controlled to be within the above range, which helps to match the above testing method of the present disclosure, so as to simply and conveniently obtain the morphology and position of the solidification front at different moments in the semi-continuous casting process. Of course, those skilled in the art may also adjust the above specific conditions according to actual conditions, which will not be repeated here.

In one embodiment of the present disclosure, the cooling water is used to cool in the semi-continuous casting process, a flow rate of the cooling water is 4 m³/h to 6 m³/h, and the temperature of the cooling water is 20 °C to 28 °C.

The flow rate and temperature of the cooling water are controlled to be within the above range, so that the solidification rate of the aluminum alloy melt of the present disclosure is more matched with the above testing method of the present disclosure, which helps to further improve the accuracy of the above testing method of the present disclosure.

In one embodiment of the present disclosure, the grain refiner is a rod-shaped grain refiner, the rod-shaped grain refiner is selected from any one or more of Al-5Ti-B, Al-3Ti-B, Al-3Ti-0.15C, and/or the length of the rod-shaped grain refiner is 10 cm to 20 cm.

Preferably, the above grain refiner has an excellent refining effect and can melt more quickly after being added to the flow channel 5.

The beneficial effects of the present disclosure will be further illustrated below in conjunction with embodiments.

Embodiment 1

Measurement was performed with reference to a schematic diagram of a measuring flow for morphology and position of a solidification front in a casting process of an aluminum alloy shown in Fig. 1.

The testing method of the present disclosure mainly included the following five stages.

1) A grain refiner 2 was selected and preheated, that is, in this embodiment, an ingot to be measured was a 7050 alloy round ingot, and in the casting process, Al-5Ti-B was selected as the grain refiner and was preheated in a resistance furnace to display the morphology and position of the solidification front in the casting process by enhancing a grain refining effect. The grain refiner was preheated, that is, before casting, in order to ensure that the grain refiner could melt quickly after being added to a melt at the end of a flow channel, a plurality of rod-shaped grain refiners Al-5Ti-B with a length of 10 cm to 20 cm were placed in the resistance furnace and were preheated to 450 °C for heat preservation by using the resistance furnace.

2) Melting and melt treatment were performed, that is, an industrial pure aluminum ingot and an alloy ingot thereof were placed in an induction furnace at 700 °C for melting, the alloy was transferred to a heat-insulating standing furnace after melting, furnace refining, degassing and other treatments were performed on the aluminum alloy melt 1, and after standing for 10 min to 20 min, semi-continuous casting was performed when the temperature of the melt dropped to 720 °C.

3) A rod-shaped grain refiner was added, that is, in this embodiment, the ingot to be measured for the morphology and position of the solidification front in the casting process was a $\phi 154$ mm 7050 round ingot, and the semi-continuous casting process of the ingot was as follows.

Before the semi-continuous casting begun, the change range of the flow rate of cooling water was set to 6m³/h, the initial casting speed of a casting machine was 60 mm/min, and the speed was linearly increased to 100 mm/min after the start of the casting process. When the length of the ingot was 1000 mm, the continuous stable stage begun, and the preheated grain refiner was added into the melt at the end of a flow channel 5. The mass of the preheated grain refiner was equal to $10^{-3} \times 0.5 \rho \pi V_{\text{cast}} (t_B - t_A) \phi^2$, that is, the mass of the preheated grain refiner was 5 kg. At this time, the maximum distance between the aluminum alloy ingot in a crystallizer and the bottom of the crystallizer was recorded to be

1900 mm, and the preheated grain refiner entered the crystallizer together with the aluminum alloy melt in the flow channel 5.

4) The morphology and position of the solidification front were displayed.

After the casting was completed, a section of 900 mm to 1100 mm of the aluminum alloy ingot 3 was taken and longitudinally sectioned along a center line, the morphology and position of the solidification front 4 after polishing and corrosion with 30% NaOH solution were shown in Fig. 2, and the measured depth of the solidification front was about 78 mm.

Embodiment 2

The difference from Embodiment 1 is that the diameter ϕ of the cross section of a casting mold was 50 mm, the casting speed v_{cast} was 100 mm/min, and the mass of the preheated grain refiner was equal to $10^{-3} \times 2.5 \rho \pi v_{\text{cast}} (t_B - t_A) \phi^2$, that is, the mass of the preheated grain refiner was 2.6 kg. After the casting was completed, a section of 950 mm to 1050 mm of the aluminum alloy ingot 3 was taken and longitudinally sectioned along the center line, the morphology and position of the solidification front 4 after polishing and corrosion with 30% NaOH solution were measured, and the measured depth of the solidification front was about 25 mm.

Embodiment 3

The difference from Embodiment 1 is that the diameter ϕ of the cross section of a casting mold was 200 mm, the casting speed v_{cast} was 100 mm/min, and the mass of the preheated grain refiner was equal to $10^{-3} \times 2.5 \rho \pi v_{\text{cast}} (t_B - t_A) \phi^2$, that is, the mass of the preheated grain refiner was 8 kg. After the casting was completed, a section of 850 mm to 1150 mm of the aluminum alloy ingot 3 was taken and longitudinally sectioned along the center line, the morphology and position of the solidification front 4 after polishing and corrosion with 30% NaOH solution were measured, and the measured depth of the solidification front was about 100 mm.

Embodiment 4

The difference from Embodiment 1 is that a mass ratio of the preheated grain refiner to the aluminum alloy melt flowing through the flow channel was 2: 1 kg/t. After the casting was completed, a section of 900 mm to 1150 mm of the aluminum alloy ingot 3 was taken and longitudinally sectioned along the center line, the morphology and position of the solidification front 4 after polishing and corrosion with 30% NaOH solution were measured,

and the measured depth of the solidification front was about 78 mm.

Embodiment 5

The difference from Embodiment 1 is that a mass ratio of the preheated grain refiner to the aluminum alloy melt flowing through the flow channel was 10: 1 kg/t. After the casting was completed, a section of 900 mm to 1100 mm of the aluminum alloy ingot 3 was taken and longitudinally sectioned along the center line, the morphology and position of the solidification front 4 after polishing and corrosion with 30% NaOH solution were measured, and the measured depth of the solidification front was about 78 mm.

Embodiment 6

The difference from Embodiment 1 is that a mass ratio of the preheated grain refiner to the aluminum alloy melt flowing through the flow channel was 1: 1 kg/t. After the casting was completed, a section of 900 mm to 1100 mm of the aluminum alloy ingot 3 was taken and longitudinally sectioned along the center line, the morphology and position of the solidification front 4 after polishing and corrosion with 30% NaOH solution were measured, and the measured depth of the solidification front was about 78 mm.

Embodiment 7

1) A grain refiner 2 was selected and preheated, that is, in this embodiment, an ingot to be measured was a 7050 alloy round ingot, and in the casting process, Al-5Ti-B was selected as the grain refiner and was preheated in a resistance furnace to display the morphology and position of the solidification front in the casting process by enhancing a grain refining effect. The grain refiner was preheated, that is, before casting, in order to ensure that the grain refiner could melt quickly after being added to a melt at the end of a flow channel, a plurality of rod-shaped grain refiners Al-5Ti-B with a length of 10 cm to 20 cm were placed in the resistance furnace and were preheated to 450 °C for heat preservation by using the resistance furnace.

2) Melting and melt treatment were performed, that is, an industrial pure aluminum ingot and an alloy ingot thereof were placed in an induction furnace at 700 °C for melting, the alloy was transferred to a heat-insulating standing furnace after melting, furnace refining, degassing and other treatments were performed on the aluminum alloy melt 1, and after standing for 10 min to 20 min, semi-continuous casting was performed when the temperature of the melt dropped to 720 °C.

3) A rod-shaped grain refiner was added, that is, in this embodiment, the ingot to be measured for the morphology and position of the solidification front in the casting process was a $\phi 154$ mm 7050 round ingot, and the semi-continuous casting process of the ingot was as follows:

before the semi-continuous casting begun, the change range of the flow rate of cooling water was set to $6\text{m}^3/\text{h}$, and the initial casting speed of a casting machine was $60\text{ mm}/\text{min}$. After 1 min, before entering the stable stage, the preheated grain refiner was added into the melt at the end of the flow channel 5. The mass of the preheated grain refiner was $10^{-3} \times 0.7 \rho \pi v_{\text{cast}} (t_B - t_A) \phi^2$, that is, the mass of the preheated grain refiner was 3 kg. At this time, the maximum distance between the aluminum alloy ingot in a crystallizer and the bottom of the crystallizer was recorded to be 500 mm, and the preheated grain refiner entered the crystallizer together with the aluminum alloy melt in the flow channel 5.

4) The morphology and position of the solidification front were displayed.

After the casting was completed, a section of 0 to 150 mm of the aluminum alloy ingot 3 was taken and longitudinally sectioned along a center line, the morphology and position of the solidification front 4 after polishing and corrosion with 30% NaOH solution were measured, and the measured depth of the solidification front was about 20 mm.

Comparative Embodiment 1

The commonly used method for measuring morphology and position of a solidification front was a point insertion method, that is, in a casting process, a thin wire or probe was inserted vertically from a metal liquid surface into a melt until a solid phase was touched, and then was drawn out. The position of the solidification front in the casting process was measured by measuring the length of the inserted wire or probe at different positions. Table 1 showed depth values of the solidification front measured five times using the point insertion method.

Table 1

Frequency	1	2	3	4	5
Depth of solidification front	85mm	75mm	69mm	81mm	72mm

Comparative Embodiment 2

In order to compensate for an error caused by the wire insertion method, a

thermocouple method came into being. According to the method, in the casting process, metal thermocouples were embedded in different positions inside the ingot online. The thermocouples were solidified with the ingot, and the morphology and position of the solidification front in the casting process were reflected by means of the changes in the temperature of the thermocouples at different positions. This method measured a value of the liquid cavity accurately and could quantitatively reflect the changes in the morphology and position thereof. As shown in Fig. 3, the depth of the solidification front measured by the thermocouple method was 77 mm, where T_L was a liquidus temperature and T_S was a solidus temperature.

It was to be noted that the method for measuring the depth of the solidification front in Comparative Embodiment 2 was high in accuracy, but the metal thermocouple method was complicated to operate. After the measurement was completed, the ingot could only be scrapped. In addition, the embedded thermocouple increased stress concentration points inside the ingot, which might cause the ingot to crack or even burst, and the application field was limited to a certain extent.

In Embodiment 6, the amount of preheated grain refiner added was relatively low, so that the solidification front was not as clear as in Embodiments 1, 5, and 6.

From the above description, it may be seen that the above embodiments of the present disclosure achieve the following technical effects.

Compared with the conventional testing method for the morphology and position of the solidification front, the testing method of the present disclosure is mainly as follows: after the longitudinally sectioned part of the aluminum alloy ingot is polished and corroded in a manner of excessively adding the grain refiners (the conventional amount of grain refiners required in the field is added in the aluminum alloy melt) in the casting process by using the differences between the enhanced refining effect and the refining effect of the grain refiner, the morphology and position of the solidification front in the casting process are clearly displayed by using the difference in the grain size. After adopting the testing method of the present disclosure, human errors caused by measuring the depth of the solidification front through a conventional insertion method may be avoided. In the present disclosure, the morphology and position of the solidification front are displayed more intuitively, and the accuracy of measuring results is significantly improved, so that the metal crystallization speed of the cross section of the aluminum alloy ingot, and the solidification moment and solidification speed of the solidification front in the solidification process of the aluminum

alloy melt can be more accurately reflected, so as to adjust the solidification time and solidification speed in the solidification process of the aluminum alloy melt according to the measuring results, which helps to improve the quality of the aluminum alloy ingot. In addition, the above testing method is easy to operate and easy to implement, which greatly reduces the cost.

The above is only the embodiments of the present disclosure, and is not intended to limit the present disclosure, and for those of ordinary skill in the art, various modifications and changes may be made to the present disclosure. Any modifications, equivalent substitutions, improvements, etc. within the spirit and scope of the present disclosure shall be included in the scope of protection of the present disclosure.

Claims

1. A testing method for morphology and position of solidification front in casting process of aluminum alloy, wherein the testing method comprises:

performing preheating treatment on a grain refiner to obtain a preheated grain refiner;
and

at a moment A of the casting process, mixing the preheated grain refiner with an aluminum alloy melt flowing through a flow channel, and continuously injecting a mixture into a casting mold for solidification and forming to obtain an aluminum alloy ingot;

wherein the maximum height from the aluminum alloy ingot corresponding to the moment of A to the bottom in the casting mold is recorded as H, and a center point of the cross section of the casting mold at the height H is recorded as a center point O;

after passing through the center point O and sequentially performing longitudinal sectioning, polishing, and corrosion on a part of the aluminum alloy ingot in a casting direction, the morphology and position of the solidification front at the moment A of the casting process may be revealed, the maximum height of the longitudinally sectioned part of the aluminum alloy ingot from the bottom of the casting mold is recorded as L, the diameter of the cross section of the casting mold in a direction perpendicular to the casting direction is recorded as ϕ , the length of the longitudinally sectioned part of the aluminum alloy ingot is $H'=L-H$, and H' is 0.1ϕ to 2ϕ .

2. The testing method according to claim 1, wherein the mass of the preheated grain refiner and the diameter ϕ of the cross section of the casting mold satisfy the following relationship: the mass of the preheated grain refiner is equal to $10^{-3} \times (0.5 \sim 2.5) \rho \pi v_{\text{cast}} (t_B - t_A) \phi^2$, where ρ represents the density of the aluminum alloy melt, t_A represents the time of the moment A, the time after the moment A is a moment B, the time of the moment B is represented by t_B , and v_{cast} represents a casting speed in the casting mold.

3. The testing method according to claim 1 or 2, wherein a mass ratio of the preheated grain refiner to the aluminum alloy melt flowing through the flow channel is 2: 1 kg/t to 10: 1 kg/t.

4. The testing method according to claim 1 or 2, wherein, in the casting process, the

casting process after the casting speed is a fixed value is a stable stage, the preheated grain refiner is respectively added at different moments in the stable stage, and the morphology and position of the solidification front at different moments in the stable stage are measured, wherein the thickness H' of the longitudinally sectioned part of the aluminum alloy ingot is 1ϕ to 2ϕ , and/or the depth of the solidification front in the stable stage is 0.5ϕ to 1.5ϕ .

5. The testing method according to claim 1 or 2, wherein, in the casting process, the casting process before the casting speed is a fixed value is an initial stage, the preheated grain refiner is respectively added at different moments in the initial stage, and the morphology and position of the solidification front at different moments in the initial stage are measured, wherein the thickness H' of the longitudinally sectioned part of the aluminum alloy ingot is 0.1ϕ to 1ϕ , and/or the depth of the solidification front in the initial stage is 0 to 1ϕ .

6. The testing method according to claim 1 or 2, wherein the temperature of the preheating treatment is 350°C to 450°C .

7. The testing method according to claim 1 or 2, wherein the model of the aluminum alloy is 7050 or 2024.

8. The testing method according to claim 1 or 2, wherein the casting process of the aluminum alloy comprises:

sequentially performing smelting, refining, degassing and standing treatment on the aluminum raw ingot to obtain the aluminum alloy melt; and

performing semi-continuous casting on the aluminum alloy melt to obtain the aluminum alloy ingot;

the semi-continuous casting process comprises a continuous initial stage and a continuous stable stage which are sequentially performed;

the temperature of the aluminum alloy melt is 720°C to 740°C , and/or the casting speed in the continuous initial stage is 30 mm/min to 60 mm/min, and after the casting speed increases linearly to 100 mm/min to 125 mm/min within 1 min to 3 min, the continuous initial stage ends and the continuous stable stage begins.

9. The testing method according to claim 8, wherein cooling water is used to cool in

the semi-continuous casting process, a flow rate of the cooling water is 4 m³/h to 6 m³/h, and the temperature of the cooling water is 20 °C to 28 °C.

10. The testing method according to claim 1 or 2, wherein the grain refiner is a rod-shaped grain refiner, the rod-shaped grain refiner is selected from any one or more of Al-5Ti-B, Al-3Ti-B, Al-3Ti-0.15C, and/or the length of the rod-shaped grain refiner is 10 cm to 20 cm.