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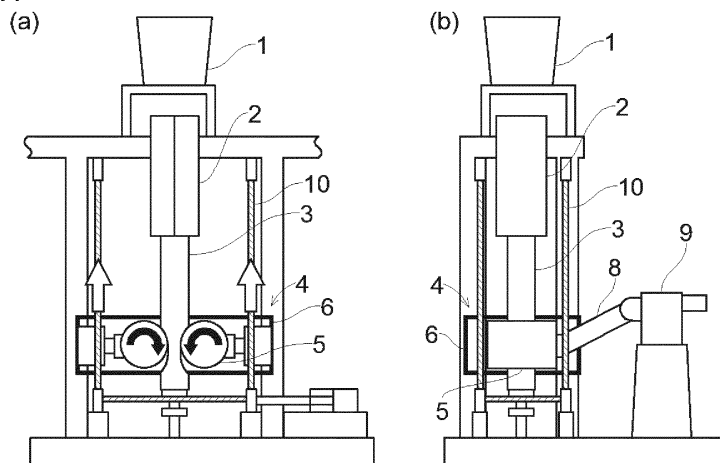
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(54) **CONTINUOUS CASTING METHOD FOR SLAB**

(57) A method of continuously casting a strand is characterized by using a movable reduction roll unit including rolls capable of reduction-rolling a strand and movable in a vertical direction from a mold along the strand, wherein, after the withdrawing of the strand is completed, the rolls are moved in a vertical direction and accordingly reduction-roll the stopped strand. The move of the rolls while reduction-rolling the strand may be in a

vertically upward direction. In addition, the transverse cross section of the strand may be of a circular shape. With this continuous casting method, it is possible to reduce centerline cavities and porosity in a central region of a strand and shrinkage cavities and centerline cavities in an upper portion of the strand, regardless of the size of its cross sectional area, at a low equipment cost and without causing deterioration of the surface quality.

FIG.1



Description

TECHNICAL FIELD

[0001] The present invention relates to a method of continuously casting a strand designed to reduce the formation of centerline cavities, porosity, and shrinkage cavities, which are internal defects, by reduction-rolling the strand using a pair of rolls, and in particular, it relates to a continuous casting method using movable rolls.

BACKGROUND ART

[0002] Currently, a typical process of manufacturing steel is carried out in such a manner that a strand is cast by a continuous casting process and the strand is subjected to processes such as slabbing, blooming, or billeting, and rolling to be formed into a final product. However, large size steel products having a large cross section such as steel products for a boiler tank and a large size die as a final product are manufactured in small lots, and they must be made from a cast steel having a large cross section. Therefore, at the present time, cast steels which are used for large size steel products are not produced by continuous casting, but are cast as a large size ingot by pouring molten steel into a mold and causing it to solidify therein. Hereinafter, this technique is referred to as "ingot process."

[0003] Casting large size ingots by an ingot process is much less efficient than by a continuous casting process even though they are manufactured in small lots. Moreover, in view of the need for feed from a feeder in an upper portion of the ingot, retention of molten steel in a sprue and a stalk, or the like, the production yield is very low. The term "feed from a feeder" as used herein refers to feeding of molten steel by an amount corresponding to the solidification shrinkage in order to prevent the formation of shrinkage cavities and shrinkage cracks due to solidification shrinkage of molten steel in ingot casting.

[0004] Furthermore, when a strand having a large cross section is cast by a continuous casting process, centerline cavities, porosity, which is a bubble defect, and segregation that occur in a central region of a strand tend to become larger. The term "centerline cavities" as used herein refers to cavity defects that occur in a central region of an alloy slab when the slab is cast. Moreover, when the casting comes to an end, after the supply of molten steel into the mold is discontinued, large shrinkage cavities such as those seen in a typical ingot process occur due to solidification shrinkage over an area from the meniscus (molten steel surface) of the strand toward the downstream side along the casting direction. These internal defects or the like not only decrease the production yield, but, in some cases, remain in the final product and can be a major cause of product defects.

[0005] As a method of producing a strand having a large cross section with good internal quality, Patent Literature 1 proposes using an inverted tapered mold in a

semi-continuous casting process for producing large size ingots such as extra thick flat ingots that are difficult to cast in conventional continuous casting machines because of their thickness. In addition, Patent Literature 1 discloses that the ingot quality can further be enhanced by heating the meniscus in the top (upper portion) of the ingot by electrical means.

[0006] Patent Literature 2 discloses that, in continuous casting of a strand, the formation of internal defects such as centerline cavities and porosity can be reduced by employing, for the strand shape, a tapered shape in which the distance between the side surfaces of the strand gradually increases toward an upper portion.

[0007] In the meantime, it is generally known that continuous casting of a strand may include a process of performing reduction rolling on the strand surface during the last stage of solidification for the purpose of reducing internal defects such as porosity and segregation. For example, Patent Literature 3 discloses a method of reduction-rolling a strand having a liquid core.

[0008] Using a tapered mold or employing a tapered shape for the strand shape as in the techniques disclosed in Patent Literatures 1 and 2 can substitute, to some extent, for the function of feed from a feeder as conventionally practiced. However, these methods require complicated casting processes and high equipment cost, but nevertheless the effect of inhibiting centerline cavities and porosity is limited, and the effect is reduced with the increase in the strand cross section. Also, the technique of heating the meniscus in the upper portion of a strand does not provide the advantage of improving the internal quality of the strand up to its central region when the strand has a long length, and further, the technique requires expensive equipment and also is uneconomical in terms of energy. Therefore, it is not considered to be a very effective technique.

[0009] In contrast, the technique of squashing internal porosity during its formation stage by reduction-rolling the strand at its surface using rolls or the like (in-line reduction rolling technique), as practiced in continuous casting by a typical continuous casting machine, is a decisive and very effective technique. However, when the in-line reduction rolling technique is employed in continuous casting of a strand having a large cross section, there are two problems as follows.

[0010] The first problem is that, in the in-line reduction rolling technique, the collapsing of the porosity formed in a strand should not be carried out at a randomly selected stage of casting, but must be carried out at an optimal time for reduction rolling. For example, when the reduction rolling of the strand is to be carried out during the formation stage of the porosity, the optimal time is considered to be the last stage of solidification between the time in which the solid fraction at the central region is about 0.5 and the time of complete solidification. When the reduction rolling is to be carried out after complete solidification, the optimal time is considered to be a time immediately after solidification at which the temperature

of the central region of the strand is still sufficiently high. Therefore, in a typical continuous casting process, reduction rolling devices such as reduction rolls are usually disposed at a specified location such as in the vicinity of the exit of the continuous casting machine.

[0011] However, when a strand having a large cross section is cast, in order to reduction-roll the strand under optimal conditions for collapsing centerline cavities and porosity by reduction rolling devices installed in the vicinity of the exit of the continuous casting machine, it is necessary to extend the length of the continuous casting machine to ensure time before the strand completely solidifies. It is to be noted that the length from the meniscus in the mold to the position of the crater end of the strand is considered to be proportional to the square of the thickness of the strand. Thus, when a case of casting a strand having a thickness of 300 mm is used as a reference, for example, casting of a strand having a thickness of 900 mm would require a continuous casting machine nine times longer, and therefore would result in requiring considerable cost for construction.

[0012] On the other hand, if it is impossible to extend the length of the continuous casting machine, one approach that may be considered to ensure the time before the strand completely solidifies is to reduce the casting speed. In general, the casting speed (the speed of the strand) at the position of the crater end is considered to be inversely proportional to the square of the thickness of the strand. Thus, when a case of casting a strand having a thickness of 300 mm at a rate of 1 m/min is used as a reference, for example, casting of a strand having a thickness of 900 mm would need to be performed at a rate of 0.11 m/min, which is a very slow speed. Such very slow speed casting causes insufficient heating at the meniscus in the mold, and leads to skinning of the meniscus, formation of a rippled casting surface due to shrinkage of the solidified shell at the meniscus, and the like, and therefore results in significant deterioration of the surface quality of the strand. In order to prevent the deterioration of the surface quality, using both plasma heating and Joule heat for meniscus heating may be considered, but it results in a high equipment cost and is uneconomical in terms of energy as described above.

[0013] The second problem is that, in the case of a strand having a large cross section, the reduction force does not sufficiently penetrate into the depth of the strand and thus it may not be possible to fully collapse centerline cavities and porosity.

CITATION LIST

PATENT LITERATURE

[0014]

Patent Literature 1: Japanese Patent Application Publication No. S62-161445

Patent Literature 2: Japanese Patent Application

Publication No. 2004-243352

Patent Literature 3: Japanese Patent Application

Publication No. 2000-288705

5 SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0015] As described above, there are problems with the techniques of conventional continuous casting methods for reducing centerline cavities and porosity in a central region of a strand having a large cross section and reducing shrinkage cavities and centerline cavities in an upper portion of the strand, in terms of equipment cost and energy and in terms of surface quality.

[0016] The present invention has been made in view of such problems with conventional techniques. Accordingly, it is an object of the present invention to provide a method which, in continuous casting, reduces centerline cavities and porosity in a central region of a strand and shrinkage cavities and centerline cavities in an upper portion of the strand regardless of the size of its cross section at a low equipment cost and without causing deterioration of the surface quality.

SOLUTION TO PROBLEM

[0017] In order to solve the above problems, the present inventors studied methods of reduction-rolling a strand in continuous casting. Consequently, they have found that, by using movable rolls to reduction-roll a strand, it is possible to perform reduction rolling at an optimal location for collapsing centerline cavities, porosity, and shrinkage cavities regardless of the size of the strand cross section. In this case, there is no need for adjusting the length of a continuous casting machine or the casting speed, which would be required in the case of using rolls fixed at a specified location, and therefore the equipment cost is very low.

[0018] The present invention has been achieved based on the above-mentioned findings, and the summaries thereof are set forth in the following (1) to (3) relating to methods of continuously casting a strand.

(1) A method of continuously casting a strand, characterized in that the method comprises: using a pair of rolls configured to interchangeably perform guiding and supporting of a strand and reduction rolling of the strand, and to be movable in a vertical direction along the strand below a mold, wherein, while the strand is being withdrawn, the pair of rolls is held in a stopped condition and guides and supports the strand, and after the withdrawing of the strand is completed, the pair of rolls is moved in a vertical direction and accordingly reduction-rolls the stopped strand.

(2) The method of continuously casting a strand according to the above (1), characterized in that the

move of the rolls while reduction-rolling the strand is in a vertically upward direction.

(3) The method of continuously casting a strand according to the above (1) or (2), characterized in that the strand has a circular transverse cross section.

ADVANTAGEOUS EFFECTS OF INVENTION

[0019] With the method of continuously casting a strand according to the present invention, it is possible to significantly reduce centerline cavities, porosity, and shrinkage cavities regardless of the size of the strand cross section as well as to cast a strand with high production yields, using a continuous casting machine for which the equipment cost is low, without causing deterioration of the surface quality.

BRIEF DESCRIPTION OF DRAWINGS

[0020]

[FIG. 1] FIG. 1 is a configuration diagram of a continuous casting machine to which the method of the present invention is applicable, wherein FIG. 1(a) is a front view thereof and FIG. 1(b) is a side view thereof.

[FIG. 2] FIG. 2 is a diagram illustrating a casting process in accordance with the continuous casting method of the present invention, wherein FIG. 2(a) shows a state at the start of casting; FIG. 2(b) shows a state during withdrawing of the strand; FIG. 2(c) shows a state in which the movable rolls have been moved to the lower end of the movable range after completion of the withdrawing; FIG. 2(d) shows a state in which the movable rolls are raised while they are reduction-rolling the strand; and FIG. 2(e) shows a state in which the reduction rolling has been completed.

[FIG. 3] FIG. 3 is a graph illustrating the relationship between the ratio of the reduction amount to the liquid core diameter of the strand (reduction amount/liquid core diameter) and the area fraction of defects, wherein FIG. 3(a) shows the results obtained in a constant region and FIG. 3(b) shows the results obtained in an upper portion of the strand.

DESCRIPTION OF EMBODIMENTS

[0021] FIG. 1 is a configuration diagram of a continuous casting machine to which the method of the present invention is applicable, wherein FIG. 1(a) is a front view thereof and FIG. 1(b) is a side view thereof. The continuous casting machine shown in FIG. 1 is of the vertical type and configured to cast a strand in a vertically downward direction. This continuous casting machine includes: a ladle 1 that contains molten steel; a mold 2 to which the molten steel is supplied from the ladle 1 via a submerged entry nozzle (not shown); and a movable re-

duction roll unit 4 that reduction-rolls a strand 3 that has been withdrawn downward from the mold 2. The mold 2 is composed of a set of half molds. The movable reduction roll unit 4 includes a pair of rolls 5 and a frame 6 that supports the rolls 5. The frame 6 is integral with the rolls 5 and vertically movable upward and downward along the strand 3 below the mold 2.

[0022] Immediately below the mold 2 are arranged support rolls 7 as shown in later-described FIG. 2 (not shown in FIG. 1), which form a support region for a solidified shell 3a of the strand 3. In the continuous casting machine, it is preferred that the solidified shell 3a be supported, at least immediately below the mold 2, at a region extending a length about one fourth to about the same as that of the mold 2. FIG. 2, which will be later described, shows an embodiment in which the support region has a length about the same as that of the mold 2.

[0023] The rolls 5 are configured to interchangeably function as pinch rolls that guide and support the strand 3 or as reduction rolls that reduction-roll the strand 3. The rolls 5 are hydraulically pressed from the back side toward the strand 3 to be brought into contact with the strand 3. Furthermore, the rolls 5 are connected to a large speed reducer 9 via a universal joint 8, and operate as drive rolls.

[0024] The frame 6 is supported in a vertically movable manner by jack shafts 10 of vertically arranged four ball screw jacks, and is also given a driving force to be movable vertically upward and downward by the jack mechanism of the jack shafts 10.

[0025] Since the rolls 5 are integral with the frame 6, they are vertically movable upward and downward along the strand 3, and therefore it is possible to change reduction rolling positions on the strand 3 and to move the rolls while they are performing reduction rolling. The move of the rolls 5 can be carried out by rotating the rolls 5 themselves in a state where they hold the strand 3 therebetween, and the direction of the move can be changed by changing the rotation direction of the rolls 5. When the rolls 5 are not in contact with the strand 3, they can be moved by the jack mechanism of the jack shafts 10.

[0026] FIG. 2 is a diagram illustrating a casting process in accordance with the continuous casting method of the present invention, wherein FIG. 2(a) shows a state at the start of casting; FIG. 2(b) shows a state during withdrawing of the strand; FIG. 2(c) shows a state in which the movable rolls have been moved to the lower end of the movable range after completion of the withdrawing; FIG. 2(d) shows a state in which the movable rolls are raised while they are reduction-rolling the strand; and FIG. 2(e) shows a state in which the reduction rolling has been completed.

[0027] With reference to FIG. 2, the continuous casting method of the present invention will be described. Firstly, casting of the strand 3 is started as shown in FIG. 2(a), and the strand 3 is continuously withdrawn as shown in FIG. 2(b). In this process, the rolls 5 are arranged imme-

diately below the mold 2, or actually immediately below the support rolls 7, and are used as pinch rolls. After the strand 3 has been withdrawn up to the limitation of the continuous casting machine, the strand 3 is stopped to complete the withdrawing. Then, the rolls 5 are moved to the lowermost end of the movable range as shown in FIG. 2(c). Thereafter, they are held waiting until the temperature of the central region of the strand 3 and the thickness of the solidified shell 3a reach optimal conditions for reduction rolling.

[0028] After the state of the strand 3 has reached optimal conditions for reduction rolling, the rolls 5 are pressed against the strand 3 to the extent that the amount of reduction of the strand 3 reaches a predetermined amount, and the rolls 5 are rotated in the direction opposite to the direction at the time of withdrawing, whereby the rolls 5 reduction-roll the strand 3 while being raised along the axis of the strand 3 as shown in FIG. 2(d). When the solidified shell 3a contains liquid steel 3b therewithin, the liquid steel 3b is ejected onto the meniscus in the upper portion as the rolls 5 are raised while reduction-rolling the strand 3 as shown in FIG. 2(e). The amount of ejected molten steel is not so large in the case where the strand has a circular transverse cross section compared to a case where the cross section is of a different shape, although it depends on the size of the liquid core at the time of reduction-rolling of the strand. That is, the amount of ejected molten steel is approximately within the capacity of the mold 2. On the other hand, when raising the rolls 5 while performing reduction rolling after the strand 3 has been completely solidified up to the core, there is of course no ejection of liquid steel.

[0029] By using the movable reduction roll unit 4 to reduction-roll the strand 3 as described above, it is possible to efficiently reduction-roll the entire strand 3 and collapse centerline cavities and porosity regardless of the size of the cross section of the strand 3. The reduction rolling of the strand 3 may be performed continuously or intermittently only for portions that need reduction-rolling.

[0030] The conditions for reduction rolling of the strand 3 can be varied by changing the speed at which the rolls 5 are raised. For example, by setting the speed for raising the rolls 5 to be the same as the speed for withdrawing the strand 3, it is possible to reduction-roll the entire strand 3 under the same conditions. The reason for this is as follows. Even after the reduction rolling by raising the rolls 5 is started, solidification of the liquid steel within the strand 3 proceeds with time to gradually diminish the liquid core. When the speed for raising the rolls 5 is set to be the same as the speed for withdrawing the strand 3, the length of time between the casting and the reduction rolling is constant at any reduction rolling position, and therefore the size of the liquid core is maintained substantially constant for all reduction rolling positions. It is to be noted that the speed for raising the rolls 5 may not necessarily be the same as the speed for withdrawing the strand 3.

[0031] When the target for inhibition is only the forma-

tion of shrinkage cavities and centerline cavities below the meniscus, the rolls 5 may be raised to a predetermined position near the lower end of the mold 2 without reduction-rolling the strand 3, and then, from the position, the rolls 5 may perform reduction rolling on the strand 3 while being raised to an upper predetermined position. Conversely, the rolls 5 may be raised to the upper predetermined position above the predetermined position near the lower end of the mold 2 without reduction-rolling the strand 3, and then, from the position, the rolls 5 may perform reduction rolling on the strand 3 while being lowered to the predetermined position near the lower end of the mold 2.

[0032] With the above steps, an entire process from withdrawing of the strand to reduction rolling by raising the rolls is completed. Thus, a subsequent casting may be carried out by repeating the process shown in FIG. 2 again after the strand is taken out.

[0033] As described above, the use of movable rolls makes it possible to cast a strand having good internal quality, without replacing the continuous casting machine, regardless of the size of the strand cross section, at a low equipment cost and without causing deterioration of the surface quality. Furthermore, since the process is a continuous casting process, higher production yields than by ingot processes are achieved in casting strands.

[0034] In the description above, a continuous casting process using a vertical type continuous casting machine has been described, but the type of continuous casting machines to which the present invention is applicable is not limited to the vertical type. The present invention may also be applicable to other forms of continuous casting machines such as those of the vertical bending type or the arcuate curved type as long as they have a section where casting can be performed in a vertically downward direction from immediately below the mold.

[0035] The type of strand to which this casting is applied is preferably a strand having a circular transverse cross section. When a strand having a circular transverse cross section is reduction-rolled by a pair of flat rolls, the solidified shell excluding portions that are in contact with the pair of rolls is not greatly deformed, and consequently deformation of only the portions that are in contact with the pair of rolls is sufficient to inhibit centerline cavities and porosity that are formed in a central region of the strand. Therefore, it is possible to efficiently collapse centerline cavities and porosity with a smaller reaction force of the reduction rolling.

[0036] Furthermore, when a movable reduction roll unit is included in a continuous casting machine, it is very difficult to install support rolls for a strand and roller aprons that hold the support rolls, which are installed in conventional continuous casting machines, because they geometrically interfere with the movable reduction roll unit. If support rolls are not installed, strand bulging may occur after static pressure of the liquid steel within the strand is applied to the solidified shell. However, when the transverse cross section of the strand is circular, the

likelihood of the occurrence of bulging can be reduced even when the solidified shell is subjected to static pressure of the molten steel in the absence of support rolls to some extent.

[0037] The reduction rolling of a strand may be carried out in a state where the liquid core remains within the strand, or in a state where the strand is completely solidified. Depending on the grade of the steel to which the casting is applied, internal cracking may occur in the strand when it is reduction-rolled with the liquid core remaining therein. Thus, in such a case, reduction-rolling may be performed after the strand is completely solidified. Also, in some grades of steel, centerline cavities and porosity that will occur are not relatively large, and therefore, in this case, collapsing of centerline cavities and porosity can be sufficiently achieved even with reduction rolling after the complete solidification.

EXAMPLES

[0038] To verify the advantageous effects of the method of continuously casting a strand of the present invention, the following casting tests (a preliminary test and a final test) were conducted.

1. Preliminary Test

1-1. Test Conditions

[0039] The strand to be cast was a small-size strand having a diameter of 300 mm and a length of 1800 mm, and the steel grade selected was a 13% Cr steel, which has a tendency to have increased centerline cavities and porosity. A continuous casting machine of the type shown in FIG. 1 was used. However, support rolls for supporting the solidified shell of the strand were not provided. The movable reduction roll unit included rolls having a diameter of 450 mm with a roll force of up to 100 t and a maximum roll torque of 50 t·m. The speed for raising the movable reduction roll unit for reduction rolling was set to 0.8 m/min and, after the casting of the strand over the entire length was completed, reduction rolling was performed on the strand over the entire length. The amount of reduction of the strand was 20 to 70 mm in terms of a reduction in the strand diameter in the rolling direction. It is to be noted that the cross section of the strand was flattened as a result of the reduction rolling.

[0040] The diameter of the liquid core (hereinafter referred to as "liquid core diameter") at the reduction rolling positions was 70 mm or 110 mm. These values were determined by defining the solid-liquid interface by an isotherm corresponding to a solid fraction of 0.8. The position of the interface where the solid fraction becomes 0.8 was determined by one-dimensional unsteady heat transfer and solidification analysis of the cylindrical cross section. The calculation results were compared against the results of measurement of the temperature of the strand surface, measurement of the temperature inside

the strand by a thermocouple, and measurement of the liquid core diameter by addition of a tracer such as S, thereby confirming that the analysis is sufficiently accurate.

1-2. Test Results

[0041] After completion of the test, each strand was cut so that the longitudinal section passing through the center of the strand was exposed. The sectioned surface was ground and polished, and then investigation was made on the formation of centerline cavities, porosity, and shrinkage cavities. These defects appeared as voids in the section of the strand, and the extent of the defects was calculated as an area percentage of voids (fraction of voids) in the entire area of the cross section. The fraction of voids was divided by the fraction of voids of a strand which was cast separately from the reduction rolled strand without being subjected to reduction rolling by rolls (hereinafter referred to as "non-reduction-rolled strand"), and the result was defined as the area fraction of defects and was used as an index showing the extent of the formation of defects. The area of voids was measured using multipurpose image and photograph analysis software, but other methods may be used for the measurement.

[0042] FIG. 3 is a graph illustrating the relationship between the ratio of the reduction amount to the liquid core diameter of the strand (reduction amount/liquid core diameter) and the area fraction of defects, wherein FIG. 3(a) shows the results obtained in a constant region and FIG. 3(b) shows the results obtained in an upper portion of the strand. The upper portion of the strand refers to a region where centerline cavities and shrinkage cavities are formed in the case of a non-reduction-rolled strand, and in the case of a reduction-rolled strand, it refers to a region corresponding to the region in a non-reduction-rolled strand where centerline cavities and shrinkage cavities are formed. The constant region refers to a region other than the upper portion of the strand.

[0043] As shown in FIG. 3(a), it has been found that, when the value of the reduction amount/liquid core diameter is increased, a significant reduction of centerline cavities and porosity can be achieved. In addition, from FIG. 3(b), it has been observed that an even greater effect of reducing defects is produced in an upper portion of a strand than in a constant region.

2. Final Test

2-1. Studies of Casting Conditions

[0044] Based on the results of the preliminary test, casting conditions were studied for a case where the quantity of molten steel is increased as the final test. The strand to be cast was a strand having a diameter of 800 mm and a length of 10 m, and the steel grade selected was a 13% Cr steel. The amount of molten steel used in

the casting of this strand was about 40 t. This is equivalent to the amount for four ingots which are cast by a typical ingot process (the amount of molten steel: 10 t). In typical ingot casting, feed from a feeder is used to prevent the formation of shrinkage cavities and centerline cavities in an upper portion of the ingot. For the feed, molten steel in an amount of 10 % of the mass of the ingot is required per ingot, and therefore additional 4 t of molten steel will be required. After the ingot is cast, the feed portion needs to be cut off, and therefore a loss is incurred accordingly, but no such loss is incurred in continuous casting processes.

[0045] A continuous casting machine of the type shown in FIG. 1 was used. The mold used was a water-cooled mold made of copper having a diameter of 800 mm and a length of 800 mm. Immediately below the mold were provided support rolls with the length of the support region being 800 mm. The movable reduction roll unit included rolls having a diameter of 650 mm. Cooling of the strand was carried out by water spray cooling at a flow rate of 0.2 L/kg-steel. Withdrawing of the strand was carried out at a casting speed of 0.25 m/min, and the withdrawing was discontinued when the length of the strand became 10 m. The other test conditions than that were the same as those for the preliminary test as described above.

[0046] According to heat transfer and solidification analysis that was performed on continuous casting under the above conditions, it was estimated that the surface temperature of the strand when the withdrawing was discontinued was about 1220°C at a location 4 m in the casting direction from the meniscus in the mold and about 980°C at a location of 10 m. The liquid core diameter at this point of time was estimated to be about 620 mm at the location of 4 m from the meniscus and 500 mm at the location of 10 m with the solid fraction of 0.8 being used as a reference. Based on the analysis results, the amount of reduction of the strand by the movable reduction roll unit was set to 225 mm, and the speed for raising the movable reduction roll unit was set to 0.25 m/min. This speed for raising the rolls is the same as the speed for withdrawing the strand, and therefore the conditions for reduction rolling (the liquid core diameter and the surface temperature of the strand at the location to be reduction-rolled) are uniform over the entire region of the strand.

[0047] In this case, the liquid core diameter was about 500 mm and the surface temperature was 980°C at the location to be reduction-rolled at the start of reduction rolling. When the reduction amount is 225 mm with respect to the liquid core diameter of 500 mm, the value of the reduction amount/liquid core diameter is 0.45. Thus, it is estimated from FIG. 3, which shows the results of the preliminary test, that the area fraction of defects will be significantly reduced both for the constant region and for the upper portion of the strand, at 20% and 4.8%, respectively. The diameter of the rolls included in the movable reduction roll unit is 650 mm, and the deformation resistance of a 13% Cr steel, which is the steel to be

cast, is 6 kgf/mm². Thus, assuming that the contact angle between the roll and the strand is 32°, the necessary roll force is 650 t.

2-2. Test Results

[0048] The strands that were cast under the above conditions had less centerline cavities, porosity, and shrinkage cavities than strands that were cast without the use of a movable reduction roll unit, and thus exhibited good internal quality and surface quality. In addition, higher production yields were obtained than in the casting of ingots of a comparable size by the ingot process.

INDUSTRIAL APPLICABILITY

[0049] With the method of continuously casting a strand according to the present invention, it is possible to significantly reduce centerline cavities, porosity, and shrinkage cavities regardless of the size of the strand cross section as well as to cast a strand with high production yields, using a continuous casting machine for which the equipment cost is low, without causing deterioration of the surface quality.

REFERENCE SIGNS LIST

[0050] 1: ladle, 2: mold, 3: strand, 3a: solidified shell, 3b: liquid steel, 4: movable reduction roll unit, 5: roll pair, 6: frame, 7: support rolls, 8: universal joint, 9: large speed reducer, 10: jack shaft

Claims

1. A method of continuously casting a strand, **characterized in that** the method comprises:

using a pair of rolls configured to interchangeably perform guiding and supporting of a strand and reduction rolling of the strand, and to be movable in a vertical direction along the strand below a mold,

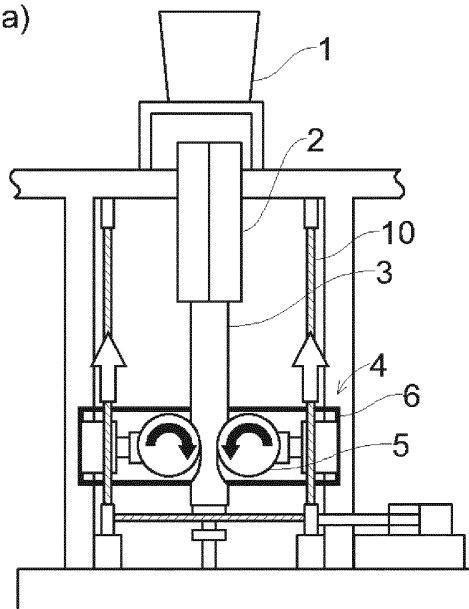
wherein, while the strand is being withdrawn, the pair of rolls is held in a stopped condition and guides and supports the strand, and after the withdrawing of the strand is completed, the pair of rolls is moved in a vertical direction and accordingly reduction-rolls the stopped strand.

2. The method of continuously casting a strand according to claim 1, **characterized in that** the move of the rolls while reduction-rolling the strand is in a vertically upward direction.

3. The method of continuously casting a strand according to claim 1 or 2, **characterized in that** the strand has a circular transverse cross section.

FIG.1

(a)



(b)

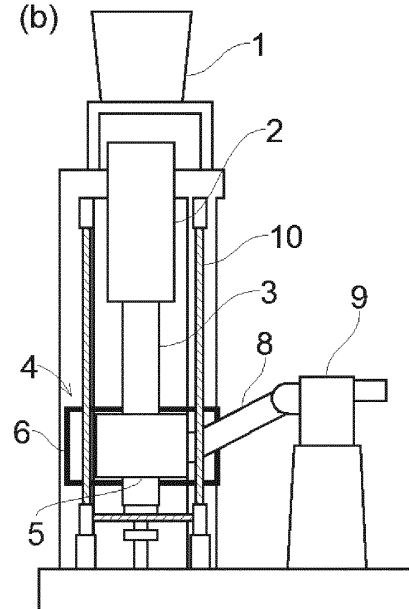


FIG.2

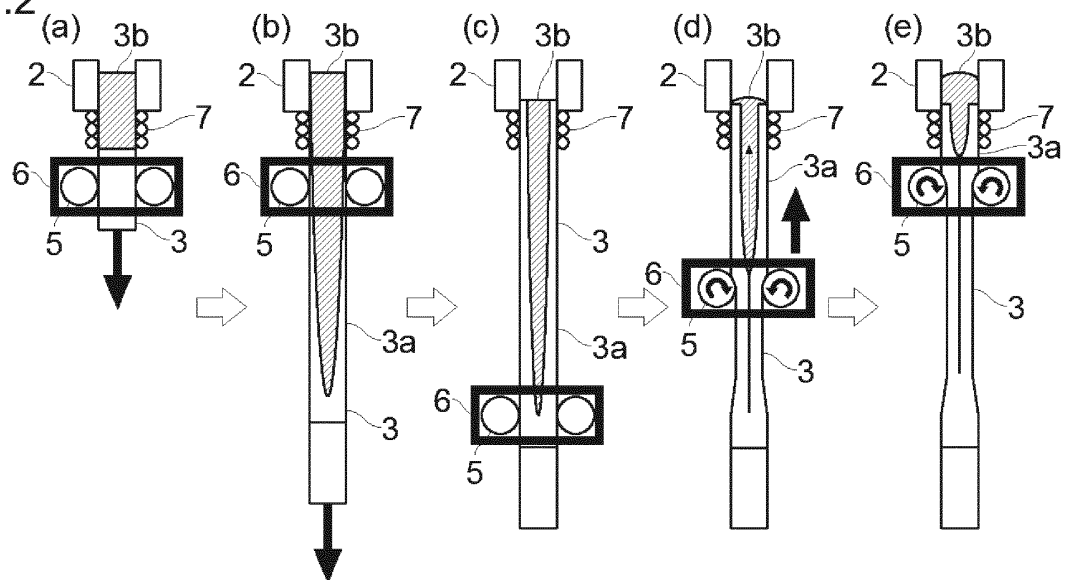
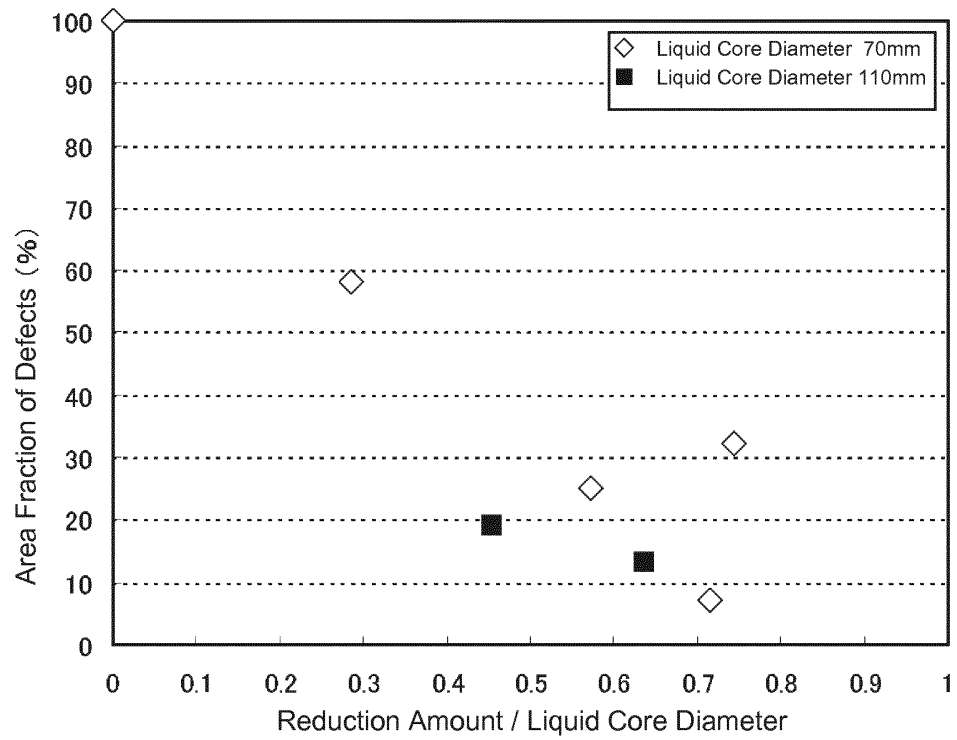
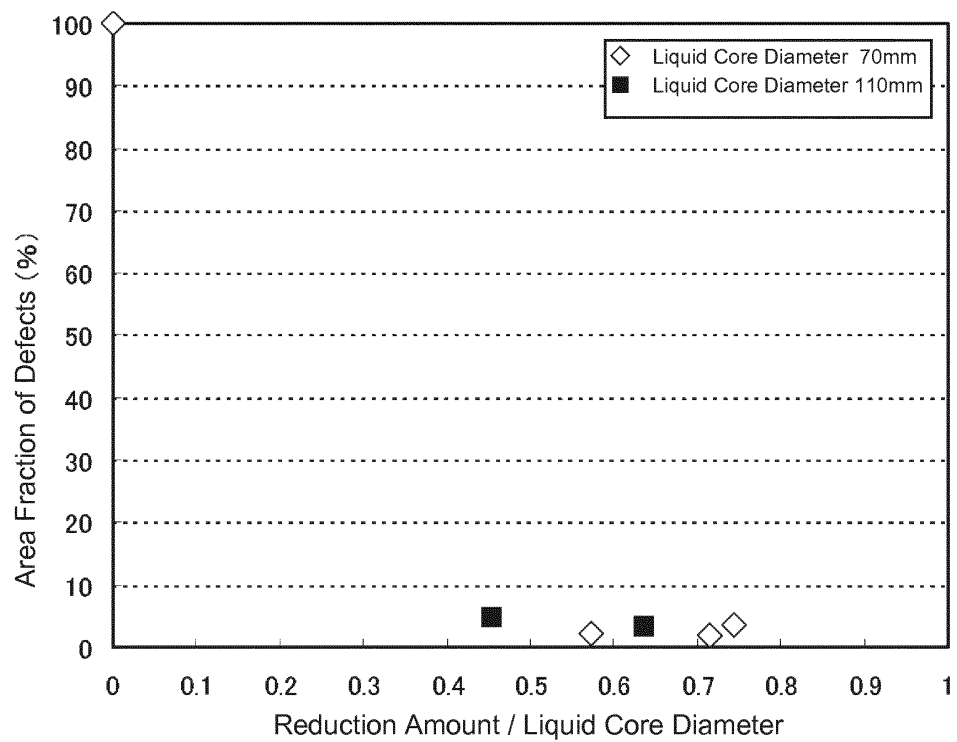


FIG.3

(a)



(b)



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2012/003388

A. CLASSIFICATION OF SUBJECT MATTER

B22D11/128(2006.01) i, B22D11/00(2006.01) i, B22D11/20(2006.01) i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B22D11/00-B22D11/22

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2012
Kokai Jitsuyo Shinan Koho	1971-2012	Toroku Jitsuyo Shinan Koho	1994-2012

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 6-190521 A (Sumitomo Metal Industries, Ltd.), 12 July 1994 (12.07.1994), claims; paragraphs [0010], [0014], [0016], [0025]; fig. 1 (Family: none)	1-3
Y	JP 8-206803 A (Daido Steel Co., Ltd.), 13 August 1996 (13.08.1996), claims; paragraphs [0005], [0006], [0022], [0030]; fig. 2 (Family: none)	1-3

☒ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
06 July, 2012 (06.07.12)Date of mailing of the international search report
17 July, 2012 (17.07.12)Name and mailing address of the ISA/
Japanese Patent Office

Authorized officer

Facsimile No.

Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2012/003388

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2011-140044 A (Sumitomo Metal Industries, Ltd.), 21 July 2011 (21.07.2011), claims (Family: none)	1-3
A	JP 63-33163 A (Kawasaki Steel Corp.), 12 February 1988 (12.02.1988), claims (Family: none)	1-3
E, X	JP 2012-115898 A (Sumitomo Metal Industries, Ltd.), 21 June 2012 (21.06.2012), claims (Family: none)	1-3

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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- JP 2004243352 A [0014]
- JP 2000288705 A [0014]