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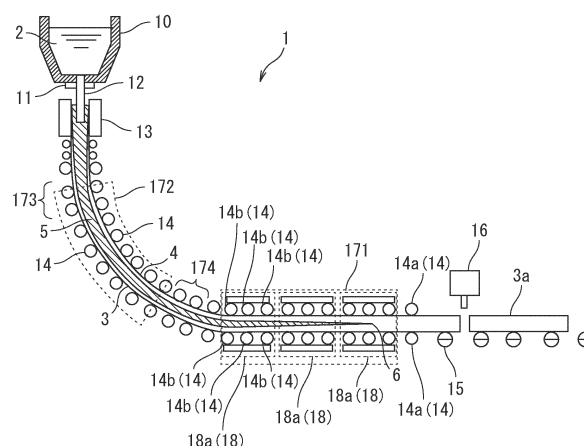
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(54) CONTINUOUS CASTING METHOD AND CONTINUOUS CASTING MACHINE FOR STEEL

(57) There are provided a continuous casting method for steel and a continuous casting machine for steel capable of reducing the overall segregation level in the cast piece width direction and reducing a variation in the cast piece width direction in a segregation degree of center segregation. A continuous casting method for steel for continuously casting steel with a continuous casting machine (1) includes: applying rolling reduction to a cast piece to be continuously cast at a rolling reduction rate of 0.3 mm/min or more and 2.0 mm/min or less in a range where a center solid phase ratio being a solid phase ratio in a thickness center of the cast piece is at least 0.2 or more and less than 1.0, in which a segment (18) deflection τ being a deflection in the thickness direction of a segment frame of the segment (18) where the rolling reduction is applied to the cast piece satisfies Equation (1). $2 \times \tau - A/(n - 1) \leq 3.25 \times 2 \times \delta \leq 1.3 \dots$ (1) In Equation (1), δ represents the actually measured bulging amount (mm), τ represents a segment deflection (mm), A represents the set rolling reduction amount of soft reduction (mm), n represents the number of cast piece supporting roll pairs present in a soft reduction zone.

FIG. 1



Description

Technical Field

- 5 **[0001]** The present invention relates to a continuous casting method for steel and a continuous casting machine for steel.

Background Art

- 10 **[0002]** In a steel solidification process, solute elements, such as carbon (C), phosphorus (P), sulfur (S), and manganese (Mn), are concentrated to an unsolidified liquid phase side due to redistribution in solidification. The concentrated solute elements result in microsegregation formed between dendrite trees. In a steel continuous casting process in a continuous casting machine, solidification shrinkage or thermal shrinkage of a cast piece, bulging of a solidified shell generated between rolls in the continuous casting machine, or the like causes the formation of cavities or the generation of a negative pressure in a thickness center part of the cast piece, so that molten steel is absorbed into this portion. However, a sufficient amount of molten steel is not present in an unsolidified layer at the end of the solidification, and therefore the molten steel concentrated by the microsegregation flows, and accumulates and solidifies in a center part of the cast piece. In a segregation spot thus formed, the concentration of the solute elements is much higher than the initial concentration of the molten steel. This is generally referred to as macrosegregation, and is also referred to as center segregation due to a site where the macrosegregation is present.

- 20 **[0003]** The center segregation deteriorates the quality of line pipe materials for transporting crude oil, natural gas, and the like. When manganese sulfides or niobium carbides are formed in a center segregation part, hydrogen entering steel by a corrosion reaction diffuses and accumulates around the manganese sulfides or the niobium carbides in the steel, and the internal pressure of the hydrogen causes cracking. Further, the center segregation part is hardened, and therefore the cracking propagates. This cracking is referred to as hydrogen-induced cracking (also referred to as "HIC") and is the primary cause of deteriorating the quality of the line pipe materials used in sour gas environments.

25 **[0004]** To address the above, a number of measures for reducing the center segregation in the cast piece or making the center segregation harmless from a continuous casting step to a rolling step have been proposed.

- 30 **[0005]** For example, PTL 1 and PTL 2 have proposed methods of casting a cast piece at the end of solidification having an unsolidified layer while the cast piece is being gradually rolling-reduced with cast piece supporting rolls with a rolling reduction amount to an extent equivalent to the sum of a solidification shrinkage amount and a thermal shrinkage amount in a continuous casting machine.

- 35 **[0006]** The technologies of gradually rolling-reducing the cast piece during casting with the rolling reduction amount to an extent equivalent to the sum of the solidification shrinkage amount and the thermal shrinkage amount in the continuous casting machine as in PTL 1 and PTL 2 are referred to as "soft reduction" or "soft reduction methods". The soft reduction technology gradually reduces the volume of the unsolidified layer by gradually rolling-reducing the cast piece using a plurality of pairs of rolls aligned in the casting direction with a rolling reduction amount corresponding to the sum of the solidification shrinkage amount and the thermal shrinkage amount. This prevents the formation of the cavities or a negative pressure part in the center part of the cast piece and simultaneously prevents the flow of the concentrated molten steel formed between dendrite trees, which reduces the center segregation in the cast piece.

- 40 **[0007]** As recent continuous casting machines, segment type continuous casting machines containing segments each including a plurality of pairs of rolls have been mainly used. In the case of the segment type continuous casting machines, a rolling reduction roll group carrying out soft reduction (also referred to as "soft reduction zone") also contains a plurality of segments. The soft reduction zone containing the segments is configured such that a predetermined rolling reduction amount is applied to a cast piece on the inlet side and the outlet side of each segment by adjusting the opening degrees between the rolls facing each other in the thickness direction of the cast piece to be larger on the inlet side than on the outlet side.

- 45 **[0008]** It is known that the shape in the cast piece width direction at a solidification completion position of the cast piece and the center segregation are closely related to each other. For example, PTL 3 has proposed a method for detecting the solidification completion position in the cast piece width direction and adjusting the molten steel flow in a mold or adjusting the width cut amount of secondary cooling such that a difference between the shortest part and the longest part at the detected solidification completion position is within the standard. When the solidification completion position varies in the cast piece width direction, the rolling reduction amount in the soft reduction zone varies in positions in the cast piece width direction, and therefore, at a position where the solidification completion position extends to the casting direction downstream side, the rolling reduction amount decreases, so that a sufficient center segregation improvement effect cannot be obtained. However, according to the method in PTL 3, the center segregation improvement effect can be obtained even when the solidification completion position varies in the cast piece width direction.

55 **[0009]** It is also known that bulging between the rolls of the cast piece also affects the center segregation. For example,

PTL 4 has proposed a continuous casting method including calculating inter-roll bulging of a cast piece in the soft reduction zone using an unsteady heat transfer solidification calculation and changing the rolling reduction rate to be applied to the cast piece corresponding to the calculated inter-roll bulging.

5 Citation List

Patent Literatures

[0010]

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PTL 1: JP H8-132203 A
PTL 2: JP H8-192256 A
PTL 3: JP 2006-198644 A
PTL 4: JP 2012-45552 A

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Summary of Invention

Technical Problem

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[0011] As described above, to improve the center segregation of the cast piece, measures have been individually taken for the rolling reduction rate in the soft reduction, the shape at the solidification completion position in the cast piece width direction, and inter-roll bulging. However, the closest quality requirement level for the continuously cast cast-piece has further increased, and a variation in the segregation degree in the cast piece width direction has also become problematic. In particular, steel materials strict about segregation, such as line pipe materials, are difficult to be used as line pipe materials when even one portion in the width direction has a large segregation at a cast piece stage.

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[0012] Even when the above-described conventional technologies are applied, problems sometimes arise for the center segregation, such as a deterioration of the overall segregation level in the cast piece width direction or an increase in a variation in the segregation degree in the cast piece width direction of the center segregation, and therefore a technology of stably reducing the center segregation has been demanded.

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[0013] Thus, the present invention has been made in view of the above-described circumstances, and aims to provide a continuous casting method for steel and a continuous casting machine for steel capable of reducing the overall segregation level in the cast piece width direction and reducing the variation in the cast piece width direction in the segregation degree of the center segregation.

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Solution to Problem

[0014]

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(1) One aspect of the present invention provides a continuous casting method for steel for continuously casting steel with a continuous casting machine of a curved type continuous casting machine or a vertical bending type continuous casting machine, including: applying rolling reduction to a cast piece to be continuously cast at a rolling reduction rate of 0.3 mm/min or more and 2.0 mm/min or less in a range where a solid phase ratio in a thickness center of the cast piece is at least 0.2 or more and less than 1.0, in which a segment deflection τ being a deflection in the thickness direction of a segment frame of a segment where the rolling reduction is applied to the cast piece satisfies Equation (1).

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$$2 \times \tau - A / (n - 1) \leq 3.25 \times 2 \times \delta \leq 1.3 \dots (1)$$

In Equation (1),

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δ represents an actually measured bulging amount (mm),

τ represents a segment deflection (mm),

A represents a set rolling reduction amount of soft reduction in a soft reduction zone where the solid phase ratio of the cast piece is 0.2 or more and less than 1.0 (mm), and

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n represent the number of cast piece supporting roll pairs present in the soft reduction zone where the solid phase ratio of the cast piece is 0.2 or more and less than 1.0.

(2) In the continuous casting method for steel described in (1) above, for a segment frame equivalent to the final solidification position, a deflection deviation σ is set to 0.2 mm or less and a lateral displacement difference t of the

segment frame is constantly set to 0.2 mm or less.

(3) In the continuous casting method for steel described in (1) or (2) above, the long side surfaces of the cast piece are bulged with a total bulging amount of 3 mm or more and 20 mm or less by stepwise increasing the roll opening degree of a plurality of pairs of cast piece supporting rolls toward the casting direction downstream side in an intentional bulging zone of the continuous casting machine, and the rolling reduction is applied to the cast piece by stepwise reducing the roll opening degree of the plurality of pairs of cast piece supporting rolls toward the casting direction downstream side in the soft reduction zone on the casting direction downstream side relative to the intentional bulging zone.

(4) One aspect of the present invention provides a continuous casting machine for steel of a curved type continuous casting machine or a vertical bending type continuous casting machine for continuously casting steel, including: a soft reduction zone where a cast piece to be continuously cast is rolling-reduced in the thickness direction, in which, in the soft reduction zone, the rolling reduction is applied to the cast piece at a rolling reduction rate of 0.3 mm/min or more and 2.0 mm/min or less in a range where a center solid phase ratio being a solid phase ratio in a thickness center of the cast piece is at least 0.2 or more and less than 1.0, and a segment deflection τ being a deflection in the thickness direction of a segment frame of a segment where the rolling reduction is applied to the cast piece in the soft reduction zone satisfies Equation (1).

Advantageous Effects of Invention

[0015] One aspect of the present invention provides the continuous casting method for steel and the continuous casting machine for steel capable of reducing the overall segregation level in the cast piece width direction and reducing the variation in the cast piece width direction in the segregation degree of the center segregation.

Brief Description of Drawings

[0016]

FIG. 1 is a schematic side view illustrating a continuous casting machine according to one embodiment of the present invention;

FIG. 2 is a schematic front view illustrating the structure of a segment;

FIG. 3 is a schematic side view illustrating the structure of the segment; and

FIG. 4 is a graph showing one example of a profile of the roll opening degrees of cast piece supporting rolls.

Description of Embodiments

[0017] The following detailed description gives a description of embodiments of the present invention with reference to the drawings. The drawings are schematic and are sometimes different from the actual ones. The embodiments described below exemplify devices and methods for embodying the technical idea of the present invention. The technical idea of the present invention does not specify materials, structures, arrangement, and the like of constituent components to the materials, structures, arrangement, and the like described below. The technical idea of the present invention can be variously altered within the technical range defined by Claims.

[0018] In one embodiment of the present invention, a continuous casting machine 1 is a device for producing a slab by continuously casting steel, the slab being a cast piece having a rectangular transverse cross-sectional shape that is the shape of a cross section orthogonal to the longitudinal direction, and is a curved type continuous casting machine or a vertical bending type continuous casting machine. The continuous casting machine 1 according to this embodiment can be applied to either type of the curved type continuous casting machine or the vertical bending type continuous casting machine because the machines are common in principle. The following description of this embodiment is given using the vertical bending type continuous casting machine as the continuous casting machine 1 as one example.

[0019] FIG. 1 illustrates a schematic side view of the continuous casting machine 1 that is a vertical bending type slab continuous casting machine used when the present invention is implemented. In this embodiment, the longitudinal direction of a cast piece 3 and the movement direction of the cast piece 3 and a solidified shell 4 in the continuous casting machine 1 are referred to as a casting direction. The lateral direction (direction orthogonal to the casting direction in a cross section of the cast piece 3 in FIG. 1) of the rectangle in the transverse cross-section (cross section orthogonal to the longitudinal direction) of the cast piece 3 is referred to as a thickness direction. The longitudinal direction (front-back direction in FIG. 1) of the rectangle in the transverse cross-section of the cast piece 3 is referred to as a width direction. The length in the thickness direction of the cast piece 3 is referred to as a thickness and the length in the width direction is referred to as a width. In the transverse cross-section of the cast piece 3, the sides facing each other in the thickness direction are longer than the sides facing each other in the width direction. The sides facing each other in the thickness

direction are referred to as long sides and the sides facing each other in the width direction are referred to as short sides.

[0020] As illustrated in FIG. 1, a mold 13 into which molten steel 2 is poured and which solidifies the molten steel 2 by cooling and forms the outer shell shape of the cast piece 3 having the rectangular transverse cross-section is placed in the slab continuous casting machine 1. At a predetermined position above the mold 13, a tundish 10 that is an intermediate vessel for relay-supplying the molten steel 2 to be supplied from a ladle (not illustrated) to the mold 13 is placed. At a bottom part of the tundish 10, a sliding nozzle 11 for adjusting the flow rate of the molten steel 2 is placed. On the lower surface of the sliding nozzle 11, an immersion nozzle 12 is placed.

[0021] Below the mold 13, a plurality of pairs of cast piece supporting rolls 14 containing supporting rolls, guide rolls, and pinch rolls are arranged. In gaps between the cast piece supporting rolls 14 adjacent to each other in the casting direction, spray nozzles (not illustrated), such as water spray nozzles or air mist spray nozzles, are arranged. A secondary cooling zone is configured in a range from the cast piece supporting rolls 14 immediately below the mold to the cast piece supporting rolls 14 at the machine end. The cast piece 3 is cooled by secondary cooling water sprayed from the spray nozzles in the secondary cooling zone while being drawn out.

[0022] The plurality of pairs of cast piece supporting rolls 14 is arranged on the casting direction downstream side from a position distant from the outlet of the mold 13 by about 1 m to 4 m in the casting direction and configures an upper straightening zone 173 in which a support and guide direction of the cast piece 3 is changed from the vertical direction to a curved direction. More specifically, the cast piece 3 in a flat sheet shape drawn out in the vertical direction from the mold 13 is gradually bent into a circular arc shape and straightened into a curved part having a constant radius in the upper straightening zone 173. In the upper straightening zone 173, a tensile stress acts on the lower surface side of the cast piece 3 and a compressive stress acts on the upper surface side. Thus, in the upper straightening zone 173, surface cracking is likely to occur on the lower surface side of the cast piece 3, and generally no surface cracking occurs on the upper surface side. In this case, the inside and the outside in the radial direction of a curved part are defined as the upper surface side and the lower surface side, respectively, with the center position in the thickness direction of the cast piece 3 as the boundary. For the surfaces on the long sides (long side surfaces) of the cast piece 3, the surface on the inside in the radial direction of the curved part is referred to as an upper surface and the surface on the outside in the radial direction of the curved part is referred to as a lower surface.

[0023] Similarly, the plurality of pairs of cast piece supporting rolls 14 arranged in the vicinity of the position where the casting direction of the curved part is parallel to the horizontal direction configures a lower straightening zone 174 where the support and guide direction of the cast piece 3 is changed from the curved direction to the horizontal direction. More specifically, the cast piece 3 in the circular arc shape is gradually bent back to the flat sheet shape and straightened into a horizontal part in the lower straightening zone 174. In the lower straightening zone 174, a tensile stress acts on the upper surface side of the cast piece 3 and a compressive stress acts on the lower surface side. Thus, in the lower straightening zone 174, surface cracking is likely to occur on the upper surface side of the cast piece 3, and generally no surface cracking occurs on the lower surface side.

[0024] On the casting direction downstream side relative to cast piece supporting rolls 14a that are cast piece supporting rolls 14 on the most casting direction downstream side, a plurality of conveying rolls 15 for conveying the cast piece 3 is placed. Above the conveying rolls 15, a cast piece cutting machine 16 for cutting a cast piece 3a having a predetermined length from the cast piece 3 to be cast is arranged.

[0025] On the casting direction upstream side and downstream side with a solidification completion position 6 of the cast piece 3 interposed therebetween, a soft reduction zone 171 is placed. The soft reduction zone 171 contains a group of the plurality of cast piece supporting rolls in which the interval (referred to as "roll opening degree") between the two cast piece supporting rolls 14 facing each other in the thickness direction with the cast piece 3 interposed therebetween and forming a pair is set to be sequentially narrowed toward the casting direction downstream side, i.e., a rolling reduction gradient is applied. In the soft reduction zone 171, the soft reduction can be applied to the cast piece 3 throughout the entire region or in a partially selected region. The soft reduction is a technology of gradually rolling-reducing the cast piece during casting with the rolling reduction amount to an extent equivalent to the sum of the solidification shrinkage amount and the thermal shrinkage amount in the continuous casting machine 1 as described above. Between the cast piece supporting rolls 14 adjacent to each other in the casting direction in the soft reduction zone 171, a spray nozzle for cooling the cast piece 3 is arranged. The cast piece supporting rolls 14 arranged in the soft reduction zone 171 are also referred to as rolling reduction rolls 14b.

[0026] In the continuous casting machine 1 illustrated in FIG. 1, the soft reduction zone 171 contains three segments 18, each containing three pairs of rolling reduction rolls 14b as one set, connected in the casting direction. In FIG. 1, the soft reduction zone 171 contains the three segments 18, but the number of the segments 18 is not particularly limited and may be one, two, or four or more. In FIG. 1, the three pairs of rolling reduction rolls 14b are arranged in one segment 18, but the number is not limited to the three pairs. The rolling reduction rolls 14b arranged in one segment may be a plurality of pairs of rolling reduction rolls 14b, and any number of rolling reduction rolls 14b may be arranged insofar as two or more pairs of rolling reduction rolls 14b are arranged. Further, although not illustrated, the cast piece supporting rolls 14 other than those in the soft reduction zone 171 also have the segment structure in the continuous casting machine 1, and particularly the

segments 18 in the soft reduction zone 171 are also referred to as soft reduction segments 18a.

[0027] As illustrated in FIGS. 2 and 3, the soft reduction segment 18a has an upper surface side frame 180, a lower surface side frame 181, and support posts 182. The upper surface side frame 180 supports the plurality (three in this embodiment) of cast piece supporting rolls 14 on the upper surface side. The lower surface side frame 181 supports the plurality (three in this embodiment) of cast piece supporting rolls 14 on the lower surface side. The upper surface side frame 180, the lower surface side frame 181, and the support posts 182 are also collectively referred to as a segment frame. The support posts 182 are posts that connect and support the upper surface side frame 180 and the lower surface side frame 181. The support posts 182 are provided on both width direction ends. When one pair of support posts 182 arranged in the width direction is set as one set, a plurality of sets of support posts 182 is provided in the casting direction. In this embodiment, one pair of support posts 182 is provided in two places of an inlet side end part and an outlet side end part in the casting direction as illustrated in FIG. 3. The support posts 182 have a mechanism of adjusting the roll opening degree by adjusting the interval in the thickness direction between the upper surface side frame 180 and the lower surface side frame 181 using a hydraulic pressure or the like.

[0028] In usual, the rolling reduction gradient in the soft reduction zone 171 is expressed by the roll opening degree reduction amount per meter in the casting direction, i.e., "mm/m" unit. Thus, the rolling reduction rate (mm/min) of the cast pieces 3 in the soft reduction zone 171 is obtained by multiplying the rolling reduction gradient (mm/m) by the cast drawing rate (m/min).

[0029] The cast piece supporting rolls 14 arranged between the lower end of the mold 13 and a liquidus crater end position of the cast piece 3 preferably configure an intentional bulging zone 172. The liquidus crater end position is a position in the casting direction in the machine of the continuous casting machine 1 where the center temperature of the cast piece 3 is the liquidus temperature of steel to be cast and is determined by a heat transfer solidification calculation (e.g., calculation method described in PTL 4) corresponding to the molten steel temperature or the cooling capacity of the continuous casting machine 1. In the intentional bulging zone 172, the cast piece supporting rolls 14 are set such that the roll opening degrees are sequentially widened for each roll pair or for a plurality of roll pairs toward the casting direction downstream side until the increase amount of the roll opening degrees reaches a predetermined value. In the cast piece supporting rolls 14 placed on the casting direction downstream side relative to the intentional bulging zone 172 and on the casting direction upstream side relative to the soft reduction zone 171, the roll opening degrees are set to a constant value or reduced to the extent corresponding to a shrinkage amount with the temperature drop of the cast piece 3.

[0030] Herein, the bulging in this embodiment refers to intentional bulging ("intentional bulging"), and hereinafter is also simply referred to as "bulging". The intentional bulging preferably starts at the stage when a solid phase ratio of a center part is 0 and ends when the total bulging amount of the long side surfaces of the cast piece (total of the bulging amounts of the upper surface and the lower surface) reaches 3 m or more and 20 mm or less. When the total bulging amount of the intentional bulging is less than 3 mm, there is a risk that the short sides of the cast piece 3 and the cast piece supporting rolls 14 come into contact with each other, posing a risk that a sufficient soft reduction cannot be applied. When bulging is intentionally performed, the total bulging amount is preferably 15 mm or less and more preferably 10 mm or less from the viewpoint of suppressing internal cracking.

[0031] FIG. 4 illustrates one example of a profile of the roll opening degrees of the cast piece supporting rolls 14 in this embodiment. In the profile of the roll opening degrees illustrated in FIG. 4, the cast piece long side surfaces are intentionally bulged by a molten steel static pressure, and the thicknesses of the center parts of the cast piece long side surfaces are increased in the intentional bulging zone 172 (area b). In the profile of the roll opening degrees illustrated in FIG. 4, the roll opening degrees are set to a constant value or reduced to the extent corresponding to a shrinkage amount with the temperature drop of the cast piece 3 on the downstream side after passing through the intentional bulging zone 172 (region c). Therefore, in the profile of the roll opening degrees illustrated in FIG. 4, the cast piece long side surfaces are rolling-reduced in the soft reduction zone 171 (area d). a and e in FIG. 4 are regions where the roll opening degrees are reduced to the extent corresponding to the shrinkage amount with the temperature drop of the cast piece 3. a' in the figure is an example of the roll opening degrees according to a conventional method including reducing the roll opening degrees to the extent corresponding to the shrinkage amount with the temperature drop of the cast piece 3.

[0032] In the intentional bulging zone 172, the roll opening degrees of the cast piece supporting rolls 14 are sequentially increased toward the casting direction downstream side, so that the long side surfaces excluding the vicinities of the short sides of the cast piece 3 are intentionally bulged following the cast piece supporting rolls 14 by a molten steel static pressure by an unsolidified layer. The long side surfaces in the vicinities of the short sides of the cast piece 3 are made to adhere to and restrained to the short side surfaces of the cast piece 3 after the solidification has completed, and therefore maintains the thickness at the time when the intentional bulging is started. Accordingly, the cast piece 3 comes into contact with the cast piece supporting rolls 14 only in bulged portions of the long side surfaces by the intentional bulging. In the soft reduction zone 171, the total rolling reduction amount is set to be equal to or less than the total bulging amount, so that only the bulged portions of the long side surfaces of the cast piece 3 are rolling-reduced, enabling efficient soft reduction. The total rolling reduction amount is a rolling reduction amount of the cast piece 3 from the start of the rolling reduction to the end of the rolling reduction in the soft reduction zone 171. The total bulging amount is the bulging amount from the start of the

intentional bulging to the end of the intentional bulging in the intentional bulging zone 172. The bulging amount is the maximum amount of the bulging of the thickness in the width direction of the cast piece 3, and is the length (mm) calculated as a difference between the maximum thickness value in the transverse cross-section of the cast piece 3 (basically, thickness in the width direction center) and the thickness on the short sides.

[0033] When the cast piece 3 is intentionally bulged, the intentional bulging zone 172 is preferably arranged between the lower end of the mold 13 and the liquidus crater end position of the cast piece 3. The reason for this is that a cast piece thickness center part entirely contains an unsolidified layer 5 (liquid phase) on the casting direction upstream side relative to the liquidus crater end position of the cast piece 3, and the solidified shell 4 of the cast piece 3 has a high temperature and low deformation resistance, and can be easily bulged. When the cast piece 3 is intentionally bulged, the bulging when the unsolidified layer 5 present inside the cast piece 3 is insufficient rather deteriorates the center segregation. However, when the bulging is performed on the casting direction upstream side relative to the liquidus crater end position of the cast piece 3, the molten steel having an initial concentration in which the solute elements are not concentrated is abundantly present inside the cast piece at this point, and the molten steel easily flows. Even when the molten steel flows, no segregation occurs, and thus the bulging at this point does not cause the center segregation.

[0034] The liquidus of the cast piece 3 is the solidification starting temperature determined by the chemical composition of the cast piece 3, and can be determined from Equation (2) below, for example.

$$T_L = 1536 - (78 \times [\%C] + 7.6 \times [\%Si] + 4.9 \times [\%Mn]) + 34.4 \times [\%P] + 38 \times [\%S] + 4.7 \times [\%Cu] + 3.1 \times [\%Ni] + 1.3 \times [\%Cr] + 3.6 \times [\%Al]) \quad (2)$$

[0035] In Equation (2), T_L is the liquidus temperature ($^{\circ}\text{C}$), $[\%C]$ is the carbon concentration of the molten steel (% by mass), $[\%Si]$ is the silicon concentration of the molten steel (% by mass), $[\%Mn]$ is the manganese concentration of the molten steel (% by mass), $[\%P]$ is the phosphorus concentration of the molten steel (% by mass), $[\%S]$ is the sulfur concentration of the molten steel (% by mass), $[\%Cu]$ is the copper concentration of the molten steel (% by mass), $[\%Ni]$ is the nickel concentration of the molten steel (% by mass), $[\%Cr]$ is the chromium concentration of the molten steel (% by mass), and $[\%Al]$ is the aluminum concentration of the molten steel (% by mass). In the study of this embodiment, low-carbon aluminum killed steel was used which contains C: 0.03% by mass or more and 0.2% by mass or less, Si: 0.05% by mass or more and 0.5% by mass or less, Mn: 0.8% by mass or more and 1.8% by mass or less, P: less than 0.02% by mass, and S: less than 0.005% by mass. However, the application range of the present invention is not limited to the component range above.

[0036] The intentional bulging zone 172 does not require any special mechanism and is configured simply by adjusting the roll opening degrees, and therefore it can be placed in any position insofar as it is in the range from the lower end of the mold 13 to the liquidus crater end position of the cast piece 3.

[0037] In the slab continuous casting machine 1 of this configuration, the molten steel 2 poured from the tundish 10 into the mold 13 through the immersion nozzle 12 is cooled in the mold 13 to form the solidified shell 4. The cast piece 3 having the solidified shell 4 as the outer shell and having the unsolidified layer 5 inside is continuously drawn out to the downward of the mold 13 while being supported by the cast piece supporting rolls 14 provided below the mold 13. The cast piece 3 is cooled by secondary cooling water in the secondary cooling zone while passing through the cast piece supporting rolls 14, and increases the thickness of the solidified shell 4. Then, the cast piece 3 increases the thicknesses of portions excluding short side end parts of the long side surfaces in the intentional bulging zone 172 and completes the solidification up to the inside at the solidification completion position 6 while being subjected to soft reduction in the soft reduction zone 171. The cast piece 3 after the completion of the solidification is cut by the cast piece cutting machine 16 to be the cast piece 3a. To the inside of the mold 13, mold powder (not illustrated) functioning as a heat insulator, a lubricant, an antioxidant, and the like is added.

[0038] In this embodiment, continuous casting is performed under the casting conditions in the soft reduction zone 171 described below. In the soft reduction zone 171, the cast piece 3 is roll-reduced (soft reduction) at a rolling reduction rate of 0.3 mm/min or more and 2.0 mm/min or less in a range where a center solid phase ratio that is the solid phase ratio in the thickness center of the cast piece 3 is at least 0.2 or more and less than 1.0. The thickness center of the cast piece 3 in this embodiment means the center in the thickness direction in the width direction position where the solid phase ratio in the thickness center part is the lowest in the transverse cross-section of the cast piece 3. In a case where the rolling reduction rate of the soft reduction when the center solid phase ratio is in the range above is less than 0.3 mm/min, a possibility of the occurrence of V-segregation increases. On the other hand, in a case where the rolling reduction rate of the soft reduction when the center solid phase ratio is in the range above exceeds 2.0 mm/min, a possibility of the occurrence of inverse V-segregation increases.

[0039] In this embodiment, in the soft reduction zone where the center solid phase ratio is in the range of at least 0.2 or more and less than 1.0, a deflection τ of the soft reduction segments 18a that are the segments 18 configuring the soft reduction zone satisfies Equation (1) below.

$$2 \times \tau - A / (n - 1) \leq 3.25 \times 2 \times \delta \leq 1.3 \dots (1)$$

In Equation (1),

δ represents an actually measured bulging amount (mm),

τ represents a segment deflection (mm),

A represents a set rolling reduction amount of soft reduction in the soft reduction zone where the center solid phase ratio of the cast piece is 0.2 or more and less than 1.0 (mm), and

n represent the number of cast piece supporting roll pairs present in the soft reduction zone where the center solid phase ratio of the cast piece is 0.2 or more and less than 1.0.

[0040] In Equation (1), the segment deflection τ is the deflection in the thickness direction in the width direction center of the segment frame and is determined from the heights in the thickness direction of both width direction end parts and a width direction center part of the segment frame. Specifically, the deflection τ is expressed as the sum of deflections τ_1, τ_2 ($\tau = \tau_1 + \tau_2$) in both the upper surface side frame 180 and the lower surface side frame 181 as indicated by the alternate long and short dash line in FIG. 2. The deflection τ is preferably the maximum value among the deflections in a plurality of places in the casting direction of the segment frame. For example, the deflection τ may be a value of the largest deflection of the deflections at least in two places on the outlet side and the inlet side in the casting direction of the segment frame. In this case, the segment deflection τ may be determined by measuring each of the deflections at casting direction positions of the two places where the support posts 182 are provided as illustrated in FIG. 3. The deflection τ of the soft reduction segment 18a may be a value measured when the cast piece 3 is actually continuously cast or may be a value measured when a similar steel grade is continuously cast with the continuous casting machine 1.

[0041] The actually measured bulging amount δ is a bulging amount after the point in time when the center solid phase ratio of the cast piece 3 changes to more than 0.0. The actually measured bulging amount δ is the bulging amount of either the upper surface or the lower surface, and is preferably an actually measured value of the bulging amount of the upper surface for ease of measurement. The bulging amounts are usually the same in the upper surface and the lower surface, and therefore the bulging amount can be determined by measuring the bulging amount of the long side surface of either one of the upper surface and the lower surface and doubling the measured bulging amount. In Equation (1), the actually measured value of the total bulging amount is expressed by multiplying the actually measure bulging amount δ by 2 as a coefficient.

[0042] The set soft reduction amount A is such an amount (set amount) that the cast piece 3 is rolling-reduced until the cast piece 3 is completely solidified from the center solid phase ratio of 0.2 or more. The set rolling reduction amount of the soft reduction is the rolling reduction amount in setting determined only by the roll profile, i.e., set roll gap.

[0043] Herein, the present inventors have confirmed that the soft reduction is not sometimes performed with the target rolling reduction amount (set rolling reduction amount) due to the influence of the segment deflection or the like in the actual soft reduction with the continuous casting machine. Then, the present inventors have found that the center segregation can be more stably reduced by using the segments 18 satisfying the relation in Equation (1) when the continuous casting is performed in the soft reduction zone 171, and thus have accomplished the present invention.

[0044] A load on the soft reduction segments 18a that is the segments 18 configuring the soft reduction zone 171 is determined by the size of the cast piece 3, the rolling reduction gradient in the soft reduction zone 171, and the ratio of the unsolidified layer 5 of the cast piece 3 to be subjected to soft reduction. To prevent the molten steel from flowing at the end of the solidification, which causes the center segregation, it is required to apply soft reduction with an amount corresponding to the solidification shrinkage amount or the thermal shrinkage amount. However, when the set rolling reduction gradient is large or the cast piece size is large, the load on the soft reduction segments 18a increases. As the load on the soft reduction segments 18a increases, the load acts in a direction where the roll opening degrees in the soft reduction segments 18a increase. Accordingly, even when the settings of the cast piece size and the rolling reduction gradient are the same, the load on the soft reduction segments 18a varies corresponding to the shape in the cast piece width direction at the solidification completion position 6, and the roll opening degrees also vary corresponding to the load. Therefore, the rolling reduction rate actually applied to the cast piece 3 also varies from the set value.

[0045] However, the soft reduction segments 18a in the soft reduction zone 171 are designed to satisfy Equation (1) when the center solid phase ratio of the cast piece 3 is in the range above, so that the rigidity of the soft reduction segments 18a can be sufficiently obtained, the soft reduction can be performed with a sufficient rolling reduction amount, and the center segregation can be more stably reduced. The set soft reduction conditions can be equally given in the width direction of the cast piece, and therefore the variation in the width direction in the segregation degree by the center segregation can be reduced and the segregation degrees in all places in width direction can be reduced. On the other hand, when the soft reduction segments 18a in the soft reduction zone 171 do not satisfy Equation (1), a sufficient rolling reduction amount cannot be reliably obtained. This sometimes results in a deterioration of the overall segregation level in the cast piece width direction of the center segregation of the cast piece 3 or an increase in the variation in the cast piece

width direction in the segregation degree. When the conventional technologies as in PTLS 1 to 4 are verified, all of the technologies are based on a major premise that the set soft reduction conditions are applied to the cast piece as they are and do not consider a deviation from the soft reduction opening degree due to a mechanical deflection of the segments or a mechanical extension of the placed posts that actually occurs.

[0046] As the casting conditions of this embodiment, it is preferable that a deflection deviation σ of the segment frame is set to 0.2 mm or less and a lateral displacement difference t of the segment frame is constantly set to 0.2 mm or less for the segments 18 equivalent to the solidification completion position 6. The deflection deviation σ is the deviation of the deflection in each of the upper surface side frame 180 and the lower surface side frame 181 of the segment 18 and is a difference between the maximum value and the minimum value of the deflections in a plurality of places in the casting direction in each of the upper surface side frame 180 and the lower surface side frame 181. More specifically, the fact that the deflection deviation σ is 0.2 mm or less means that the deflection deviation in the casting direction is 0.2 mm or less in each of the upper surface side frame 180 and the lower surface side frame 181. For example, the deflection deviation may be a difference between the deflections of an inlet side end part and an outlet side end part in the casting direction in each of the upper surface side frame 180 and the lower surface side frame 181. In this case, positions where the deflections are measured may be the positions where the support posts 182 are provided. A difference between the maximum value and the minimum value among the deflections in three or more casting direction positions may be set as the deflection deviation σ . The lateral displacement difference t is a displacement difference between both width direction ends of the segment frame. In usual, the structure of a lower portion of the segment 18 is fixed and immobile, and therefore the displacement difference between both the width direction ends in the upper surface side frame 180 of the segment 18 is the lateral displacement difference t . The displacement difference t may also be a difference between the heights of the vertical direction upper ends of one pair of support posts 182 connected to both the width direction ends of the upper surface side frame 180. The lateral displacement difference t is preferably constantly 0.2 mm or less at different positions in the casting direction. By setting the casting conditions as described above, the center segregation can be more stably reduced.

<Modification>

[0047] As described above, the present invention is described with reference to the specific embodiment, but it is not intended to limit the invention by the descriptions. Not only the disclosed embodiment but the other embodiments of the present invention including various modifications will be apparent to those skilled in the art by reference to the description of the present invention. Therefore, the embodiment of the invention described in Claims should be construed to cover embodiments including modifications thereof described in this specification alone or in combination.

[0048] For example, the support posts 182 adjust the roll opening degree in the above-described embodiment, but the present invention is not limited to such an example. For example, it may be acceptable that a support member connecting the cast piece supporting rolls 14 to the segment frame expands and contracts by a hydraulic pressure or the like to adjust the roll opening degree.

EXAMPLES

[0049] Examples performed by the present inventors are described. In Examples, to investigate influence of the casting conditions on the thickness center segregation of the cast piece 3, two types of segments 18 (frame 1 and frame 2) different in rigidity were experimentally mounted and subjected to continuous casting under various casting conditions. The casting conditions are casting conditions in a case where the continuous casting is performed by performing soft reduction with the vertically bending type continuous casting machine 1 as illustrated in FIG. 1. Then, the cast cast-piece 3 was measured for the Mn segregation degree and subjected to a hydrogen-induced cracking (HIC) test for assessment. The detailed casting conditions are as described below.

[0050] In Examples, the cast piece drawing rate was fixed to 1.1 m/min for the purpose of more efficiently applying soft reduction to the cast piece 3. The total bulging amount in the intentional bulging zone 172 was changed for each level in the range of 0.0 mm or more and 15.0 mm or less. The set rolling reduction rate in the soft reduction zone 171 was changed for each level in the range of 0 mm/min or more and 4.0 mm/min or less. The size of the cast piece 3 to be cast was set to a slab cast piece 2100 mm wide and 250 mm thick. For the segment frames of the segments 18, the frame 1 was set to have rigidity higher than that of the frame 2. The secondary cooling water amount was adjusted to be the same in all levels. The final solidification position was determined by a heat transfer solidification calculation similar to that in PTL 4.

[0051] During casting, in the soft reduction segments where the solidification completion position 6 positioned on the most downstream side in the casting direction determined in advance by a heat solidification calculation was present, the displacement of the roll opening degrees of the segment center was measured and the displacement of the support posts of the segment frame was measured using a non-contact sensor.

[0052] For the relation between the rolling reduction rate actually applied to the cast piece 3 and the segregation of the cast piece 3, after casting, the cross sections (equivalent to the longitudinal section of the cast piece) of test pieces

collected from the cast piece were corroded with picric acid, and the occurrence or non-occurrence of V-segregation or inverse V-segregation and internal cracking was investigated. In the test pieces collected from the cast piece 3, the Mn segregation in a cast piece thickness center part was analyzed by EPMA, and the Mn segregation degrees in positions of the cast piece width direction were investigated. Further, a hydrogen-induced cracking resistance test (HIC tests) were carried out in the test pieces collected from positions in the cast piece width direction.

[0053] The level conditions and the test results in Examples are shown in Table 1. Levels 1 to 13 are cases where segments with increased frame rigidity were applied. Levels 14 to 28 are cases where segments with insufficient rigidity were applied. In Examples, the frame 1, 2 different in rigidity were used for the soft reduction zone 171 and the casting conditions other than the above were set to the same conditions, and Examples were carried out. The number of the soft reduction segments 18a to be provided in the soft reduction zone 171 was set to one. In Table 1, the actually measured bulging amount is the actually measured value of the bulging amount of the cast cast-piece, a value α is a value determined by Equation (2) below, and a value β is a value determined by Equation (3) below. The set rolling reduction amount A in Equation (1) is determined by Equation (4) below, and a length L in the casting direction in the soft reduction zone 171 was set to 1.89 m from the length of the soft reduction segments 18a, and a casting rate V_c was set to 1.1 m/min. The number n of the cast piece supporting roll pairs present in the soft reduction zone 171 was set to 8 pairs from the number of roll pairs to be provided in the soft reduction segments 18a. In Table 1, the judgment indicates whether the value β is 1.3 or less, with "o" for the value β of 1.3 or less and "x" for the value β of more than 1.3. More specifically, the condition where the value β is equal to or larger than the value α and the judgment is "o" satisfies Equation (1). In Table 1, a deflection deviation of a segment displacement is the deflection deviation σ in the segments at the final solidification position, and is a value obtained by the addition of the deflection deviation σ of the upper surface side frame 180 and the deflection deviation σ of the lower surface side frame 181. The "Inlet" and "Outlet" of the segment displacement indicates the displacement of end parts (positions where the support posts 182 were placed) on the inlet side and the outlet side in the casting direction of the segments at the final solidification position. The "South" and "North" of the segment displacement indicate the displacement of end parts (positions where the support posts 182 were placed) in one end (south side end part in an actual machine) and the other end (north side end part in an actual machine) in the segment width direction. The "Difference" in the segment displacements is a difference between the displacements in the south and the north and is the lateral displacement difference t. In Examples, the segment displacement indicates the degree of the displacement of the upper end position from a reference with the upper end position of the support post 182 in a state where the segment has no deflection as the reference.

$$\alpha = 2 \times \tau - A / (n - 1) \dots (2)$$

In Equation (2),

τ represents the segment deflection (mm),

A represents the set rolling reduction amount of soft reduction in the soft reduction zone where the solid phase ratio of the cast piece is 0.2 or more and less than 1.0 (mm), and

n represents the number of cast piece supporting roll pairs present in the soft reduction zone where the solid phase ratio of the cast piece is 0.2 or more and less than 1.0.

$$\beta = 3.25 \times 2 \times \delta \dots (3)$$

In Equation (3),

δ represents the actually measured bulging amount (mm) .

$$A = V_p \times L / V_c \dots (4)$$

In Equation (4),

V_p represents the set rolling reduction rate (mm/min),

L represents the length in the casting direction of soft reduction (m), and

V_c represents the casting rate (m/min).

[Table 1]

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Level	Segment frame	Set rolling reduction rate (mm/min)	Intentional bulging amount (mm)	Rolling reduction rate result (mm/min)	Segregation form	Occurrence or non-occurrence of internal cracking	Actually-measured bulging amount (mm)	α	β	Judgment ≤ 1.3	Segment displacement (mm)						Mn segregation degree (C/C ₀ , Mn)	Variation in width direction in segregation degree σ	HIC result (CAR%)	Remarks	
											Deflection deviation	Inlet			Outlet						
												South	North	Difference	South	North	Difference				
1	Frame 1	0.50	3.0	0.45	-	Non-occurrence	0.08	0.38	0.52	○	0.25	0.52	0.53	0.01	0.28	0.29	0.01	1.052	0.020	1.1	Present Invention Example
2		0.50	5.0	0.45	-	Non-occurrence	0.15	0.28	0.98	○	0.20	0.47	0.49	0.02	0.29	0.31	0.02	1.053	0.025	0.5	Present Invention Example
3		0.50	7.0	0.47	-	Non-occurrence	0.2	0.24	1.30	○	0.18	0.45	0.46	0.01	0.28	0.29	0.01	1.054	0.020	0.1	Present Invention Example
4		0.50	10.0	0.48	-	Non-occurrence	0.12	0.20	0.78	○	0.16	0.43	0.44	0.01	0.28	0.29	0.01	1.055	0.021	0	Present Invention Example
5		1.00	3.0	0.95	-	Non-occurrence	0.16	0.45	1.04	○	0.35	0.62	0.63	0.01	0.28	0.29	0.01	1.051	0.023	0	Present Invention Example
6		2.00	3.0	1.94	-	Non-occurrence	0.2	0.31	1.30	○	0.40	0.67	0.69	0.02	0.29	0.31	0.02	1.048	0.024	0	Present Invention Example
7		0.50	10.5	0.47	-	Occurrence	0.21	0.20	1.37	×	0.16	0.43	0.45	0.02	0.29	0.46	0.17	1.065	0.025	2.5	Comparative Example
8		0.50	15.0	0.47	-	Occurrence	0.22	0.18	1.43	×	0.15	0.42	0.43	0.01	0.28	0.3	0.02	1.062	0.021	2.2	Comparative Example
9		0.50	0.0	0.12	V-segregation	Non-occurrence	0.21	0.78	1.37	×	0.45	0.72	0.77	0.05	0.32	0.37	0.05	1.070	0.028	11.2	Comparative Example
10		0.50	2.5	0.14	V-segregation	Non-occurrence	0.22	0.68	1.43	×	0.40	0.67	0.71	0.04	0.31	0.35	0.04	1.072	0.030	9.4	Comparative Example
11		0.30	3.0	0.20	V-segregation	Non-occurrence	0.19	0.03	1.24	○	0.05	0.32	0.33	0.01	0.28	0.29	0.01	1.078	0.031	5.2	Comparative Example
12		4.00	5.0	3.85	Inverse V-segregation	Non-occurrence	0.14	0.06	0.91	○	0.52	0.79	0.89	0.10	0.37	0.52	0.15	1.068	0.034	7.1	Comparative Example
13		3.00	3.0	2.94	Inverse V-segregation	Non-occurrence	0.18	0.06	1.17	○	0.43	0.70	0.77	0.07	0.34	0.41	0.07	1.065	0.028	5.8	Comparative Example
14	Frame 2	0.50	3.0	0.45	-	Non-occurrence	0.21	0.88	1.37	×	0.5	0.68	0.93	0.25	0.68	0.93	0.25	1.060	0.050	3.5	Comparative Example
15		0.50	5.0	0.45	-	Non-occurrence	0.25	0.78	1.63	×	0.45	0.63	0.93	0.3	0.63	0.94	0.31	1.061	0.055	4.5	Comparative Example
16		0.05	7.0	0.04	V-segregation	Non-occurrence	0.22	0.85	1.43	×	0.43	0.61	0.89	0.28	0.61	0.9	0.29	1.062	0.060	4.8	Comparative Example
17		0.02	10.0	0.01	V-segregation	Non-occurrence	0.3	2.00	1.95	×	1.00	1.18	1.40	0.22	0.59	0.82	0.23	1.063	0.058	5.3	Comparative Example
18		1.00	3.0	0.95	-	Non-occurrence	0.25	2.35	1.625	×	1.3	1.48	1.78	0.3	0.78	1.1	0.32	1.059	0.057	3.2	Comparative Example
19		2.00	3.0	1.94	-	Non-occurrence	0.81	0.81	5.265	×	0.65	0.83	1.18	0.35	0.83	1.21	0.38	1.056	0.055	4.1	Comparative Example
20		0.50	10.5	0.47	-	Occurrence	0.32	0.70	2.08	×	0.41	0.59	0.84	0.25	0.59	0.86	0.27	1.064	0.052	4.4	Comparative Example
21		0.50	15.0	0.47	-	Occurrence	0.51	0.68	3.315	×	0.4	0.58	0.81	0.23	0.68	0.92	0.24	1.057	0.051	5	Comparative Example
22		0.50	0.0	0.12	V-segregation	Non-occurrence	0.34	1.28	2.21	×	0.7	0.88	1.13	0.25	0.88	1.13	0.25	1.078	0.055	11.2	Comparative Example
23		0.50	2.5	0.14	V-segregation	Non-occurrence	0.63	1.18	4.095	×	0.65	0.83	1.05	0.22	0.83	1.05	0.22	1.080	0.053	10.4	Comparative Example
24		0.30	3.0	0.20	V-segregation	Non-occurrence	0.35	0.53	2.28	×	0.3	0.48	0.56	0.08	0.48	0.58	0.1	1.086	0.051	9.2	Comparative Example
25		4.00	5.0	3.85	Inverse V-segregation	Non-occurrence	0.4	0.56	2.6	×	0.77	0.95	1.37	0.42	0.95	1.43	0.48	1.076	0.048	7.1	Comparative Example
26		3.00	3.0	2.94	Inverse V-segregation	Non-occurrence	0.25	0.82	1.625	×	0.68	0.86	1.17	0.31	0.86	1.21	0.35	1.073	0.044	5.8	Comparative Example
27		0.50	15.0	0.47	-	Occurrence	0.19	0.20	1.235	○	0.16	0.43	0.45	0.02	0.29	0.46	0.17	1.056	0.025	0	Comparative Example
28		0.50	20.0	0.47	-	Occurrence	0.2	0.18	1.3	○	0.15	0.42	0.43	0.01	0.28	0.3	0.02	1.046	0.021	0	Comparative Example

[0054] As shown in Table 1, when the frame 1 and the frame 2 were compared with each other, the frame rigidity was increased, the center deflection was set to 0.4 mm or less, and the lateral displacement difference was reduced to 0.2 mm or less, resulting in an improvement of the center segregation.

[0055] The levels 1 to 6 are the conditions in the range of the present invention, and had excellent results in the segregation degree and the variation σ . Under the conditions where the rolling reduction rate in the soft reduction zone 171 was less than 0.3 mm/min of the levels 9 to 11, 16 to 17, 22 to 24, the V-segregation occurred. Under the conditions where the rolling reduction rate exceeded 2.0 mm/min of the levels 12, 13, 25, 26, the inverse V-segregation occurred.

[0056] For the center segregation, the Mn segregation degree deteriorated and the cracking and segregation area ratio (%) = Crack Area Ratio (CAR) that is the HIC result also deteriorated in those in which the V-segregation and the inverse V-segregation occurred. As the determination criteria for the center segregation, those having the Mn segregation degrees of 1.06 or less were assessed as "Good" and those having the HIC results of 2.0 or less were assessed as "Good". Accordingly, it was found that the rolling reduction rate in the soft reduction zone 171 is required to be controlled to 0.3 mm/min or more and 2.0 mm/min or less. The rolling reduction rate actually applied to the cast piece 3 was determined as the product of the rolling reduction gradient calculated from the displacement of the roll opening degrees in the soft reduction segment measured by a non-contact sensor and the cast piece drawing rate.

Reference Signs List

[0057]

- 1 slab continuous casting machine
- 10 tundish
- 11 sliding nozzle
- 12 immersion nozzle
- 13 mold
- 14, 14a cast piece supporting roll
- 14b rolling reduction roll
- 15 conveying roll
- 16 cast piece cutting machine

171	soft reduction zone
172	intentional bulging zone
173	upper straightening zone
174	lower straightening zone
5 18	segment
18a	soft reduction segment
180	upper surface side frame
181	lower surface side frame
182	support post
10 2	molten steel
3, 3a	cast piece
4	solidified shell
5	unsolidified layer
6	solidification completion position

Claims

1. A continuous casting method for steel,

the method being a method for continuously casting steel with a continuous casting machine of a curved type continuous casting machine or a vertical bending type continuous casting machine, the method comprising:

applying rolling reduction to a cast piece to be continuously cast at a rolling reduction rate of 0.3 mm/min or more and 2.0 mm/min or less in a range where a center solid phase ratio being a solid phase ratio in a thickness center of the cast piece is at least 0.2 or more and less than 1.0, wherein a segment deflection τ being a deflection in a thickness direction of a segment frame of a segment where the rolling reduction is applied to the cast piece satisfies Equation (1),

$$2 \times \tau - A / (n - 1) \leq 3.25 \times 2 \times \delta \leq 1.3 \dots (1)$$

wherein

δ represents an actually measured bulging amount (mm),

τ represents a segment deflection (mm),

A represents a set rolling reduction amount of soft reduction in a soft reduction zone where the center solid phase ratio of the cast piece is 0.2 or more and less than 1.0 (mm), and

n represent a number of cast piece supporting roll pairs present in the soft reduction zone where the center solid phase ratio of the cast piece is 0.2 or more and less than 1.0.

2. The continuous casting method for steel according to claim 1, wherein, for a segment frame equivalent to a final solidification position, a deflection deviation σ is set to 0.2 mm or less and a lateral displacement difference t of the segment frame is constantly set to 0.2 mm or less.

3. The continuous casting method for steel according to claim 1 or 2, comprising:

bulging long side surfaces of the cast piece with a total bulging amount of 3 mm or more and 20 mm or less by stepwise increasing a roll opening degree of a plurality of pairs of cast piece supporting rolls toward a casting direction downstream side in an intentional bulging zone of the continuous casting machine, wherein the rolling reduction is applied to the cast piece by stepwise reducing the roll opening degree of the plurality of pairs of cast piece supporting rolls toward the casting direction downstream side in the soft reduction zone on the casting direction downstream side relative to the intentional bulging zone.

4. A continuous casting machine for steel,

the machine being a curved type continuous casting machine or a vertical bending type continuous casting machine for continuously casting steel, the machine comprising:

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a soft reduction zone where a cast piece to be continuously cast is rolling-reduced in a thickness direction, wherein

in the soft reduction zone, the rolling reduction is applied to the cast piece at a rolling reduction rate of 0.3 mm/min or more and 2.0 mm/min or less in a range where a center solid phase ratio being a solid phase ratio in a thickness center of the cast piece is at least 0.2 or more and less than 1.0, and

a segment deflection τ being a deflection in the thickness direction of a segment frame of a segment where the rolling reduction is applied to the cast piece in the soft reduction zone satisfies Equation (1),

$$2 \times \tau - A / (n - 1) \leq 3.25 \times 2 \times \delta \leq 1.3 \dots (1)$$

wherein

δ represents an actually measured bulging amount (mm),

τ represents a segment deflection (mm),

A represents a set rolling reduction amount of soft reduction in the soft reduction zone where the center solid phase ratio of the cast piece is 0.2 or more and less than 1.0 (mm), and

n represent a number of cast piece supporting roll pairs present in the soft reduction zone where the center solid phase ratio of the cast piece is 0.2 or more and less than 1.0.

FIG. 1

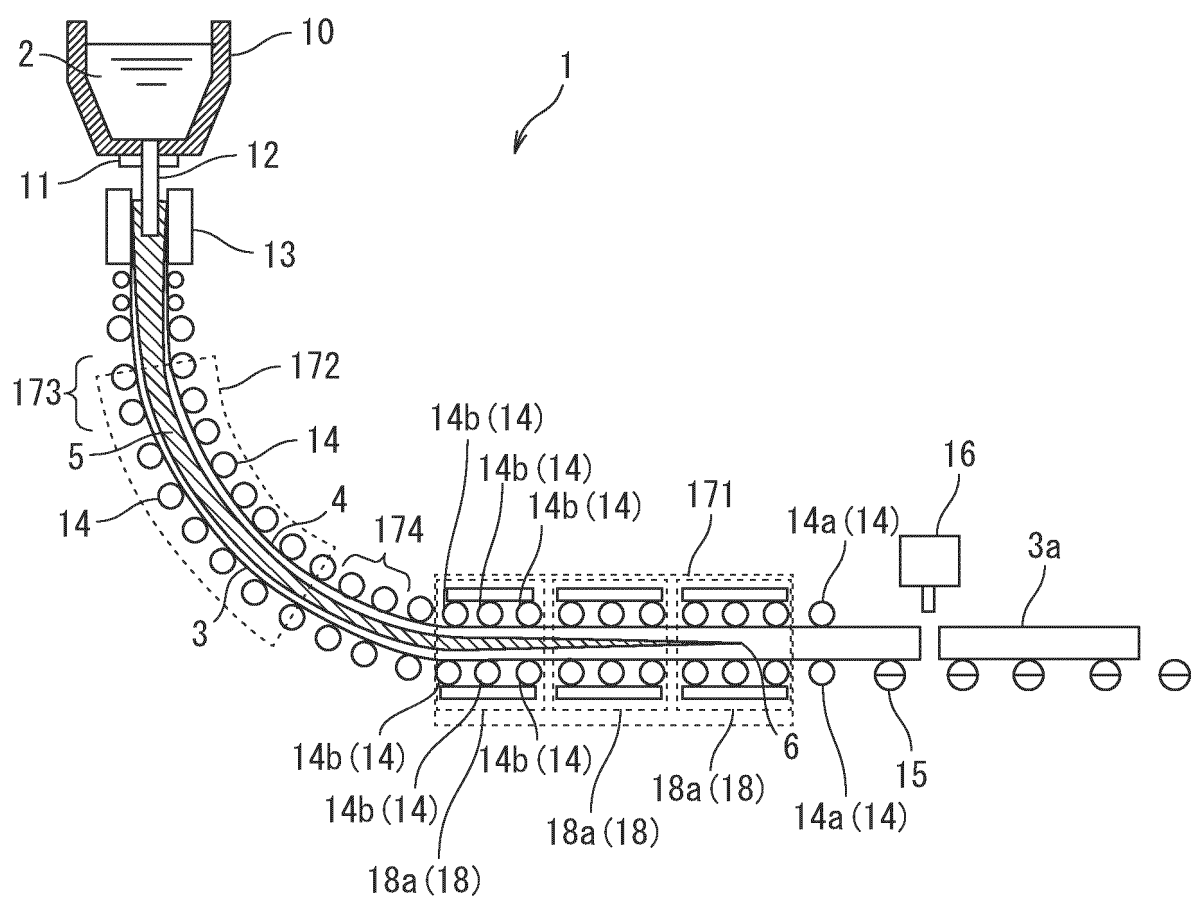


FIG. 2

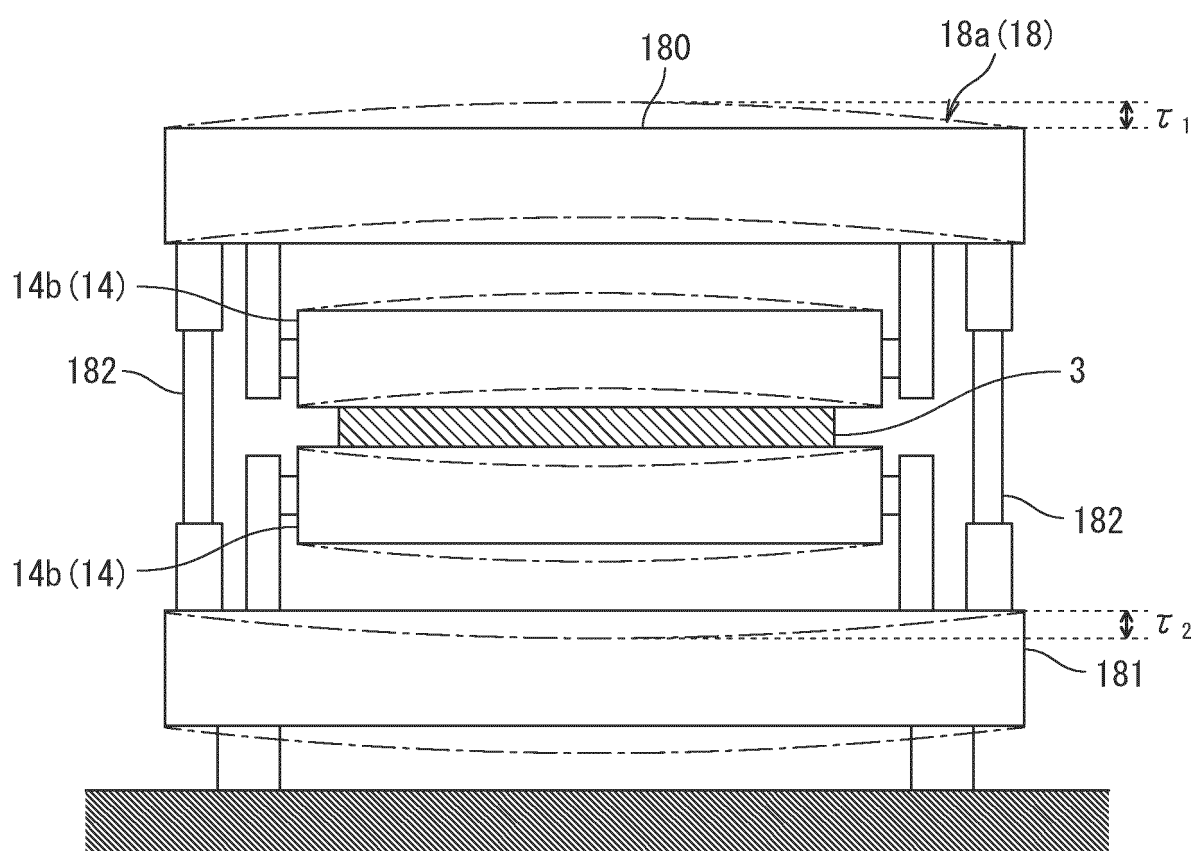


FIG. 3

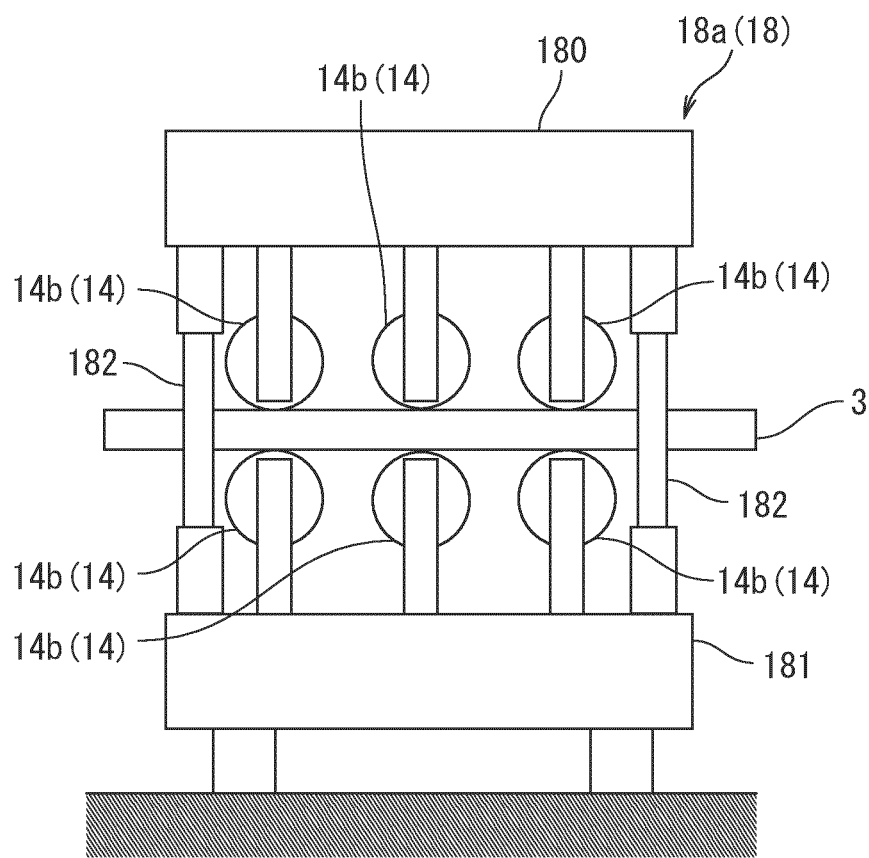
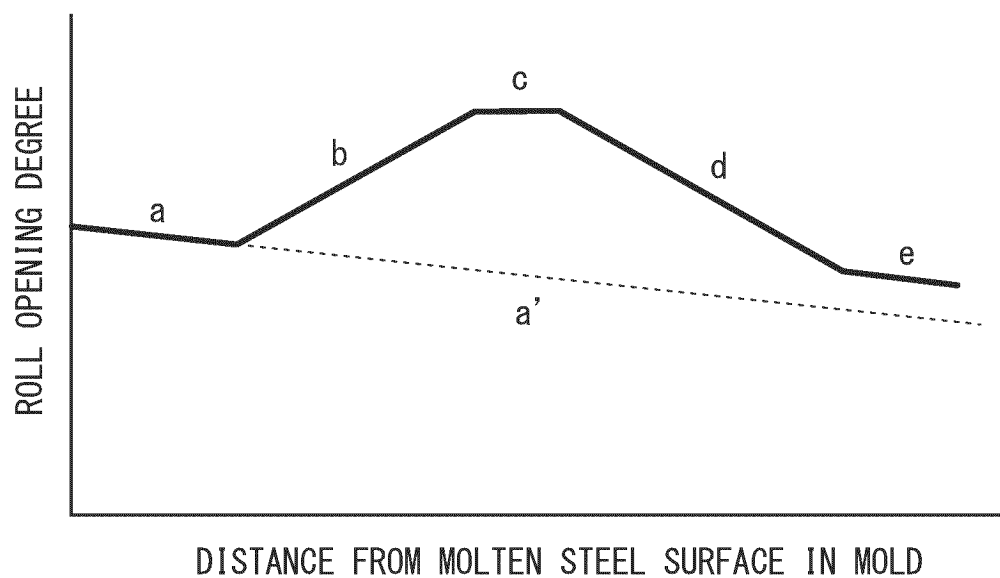


FIG. 4



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/018120

A. CLASSIFICATION OF SUBJECT MATTER

B22D 11/128(2006.01)i; **B22D 11/16**(2006.01)i

FI: B22D11/128 350A; B22D11/16 C

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)

B22D11/128; B22D11/16

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

Published examined utility model applications of Japan 1922-1996
 Published unexamined utility model applications of Japan 1971-2023
 Registered utility model specifications of Japan 1996-2023
 Published registered utility model applications of Japan 1994-2023

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.
X	JP 2016-28827 A (JFE STEEL CORP.) 03 March 2016 (2016-03-03) claims, paragraphs [0014], [0038]	4
A		1-3
A	JP 2012-45552 A (JFE STEEL CORP.) 08 March 2012 (2012-03-08) entire text, all drawings	1-4

☐ 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

“E” earlier application or patent but published on or after the international filing date

“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

“O” document referring to an oral disclosure, use, exhibition or other means

“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

12 June 2023

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