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(54) METHOD FOR CONTINUOUSLY CASTING DIFFERENT GRADES OF STEEL

VERFAHREN ZUM STRANGGIESSEN VON VERSCHIEDENEN STAHLQUALITÄTEN

PROCÉDÉ POUR LA COULÉE CONTINUE DE DIFFÉRENTES QUALITÉS D'ACIER

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Description

TECHNICAL FIELD

[0001] The present disclosure relates to a method of continuous casting heterogeneous steels, and more particularly, to a method of continuous casting heterogeneous steels which may predict and automatically cut off a mixed portion of a strand which is produced by mixing previous steel and subsequent steel in a method of continuous casting different steels.

BACKGROUND ART

[0002] A continuous casting operation of heterogeneous steels (i.e., different steels) is an operation of continuous casting by using molten steel of new steel (hereinafter, referred to as "subsequent steel") which has components different from those of molten steel of steel currently being processed (hereinafter, referred to as "previous steel"). For this purpose, the molten steel of the subsequent steel contained in a subsequent ladle is supplied to a tundish at the end of the operation of the previous steel. In this case, the molten steel of the previous steel and the molten steel of the subsequent steel are mixed in the tundish, and the mixed molten steel is injected into a mold through a submerged entry nozzle.

[0003] As a result, a mixed portion, which is produced by mixing heterogeneous steels, is indispensably generated in some portions of a cast strand, and since the mixed portion does not satisfy compositional specifications of products, the mixed portion is cut off and mostly reused as scrap metal.

[0004] Typically, in order to cut off the mixed portion generated by continuous casting of heterogeneous steels, the mixed portion has been cut to a predetermined length on the basis of a meniscus position of the strand. However, with respect to this cut-off method, since the mixed portion is cut to a predetermined length on the basis of the meniscus position of the strand regardless of various variables such as changes in steel or casting speed, a cut position of the mixed portion is not accurate. Thus, the mixed portion may be cut excessively more than the actual mixed portion so that it may be a cause of reducing productivity, or the mixed portion may be cut less than the actual mixed portion so that the product may be sold in a state in which the mixed portion is mixed.

[0005] In order to address the above limitations, lengths of the mixed portion were datafied according to types and combination of the previous steel and the subsequent steel to make as a table, and the mixed portion was cut to a cut-off length corresponding to the types and combination of the previous steel and the subsequent steel during the operation of heterogeneous steels. However, even in the above cut-off method, the mixed portion was excessively cut so that a region satisfying design specifications may be cut with the mixed portion and discarded, or there were still limitations in that all of the mixed portion may not be cut off and some of the mixed portion may be mixed in the product.

[0006] Also, as another typical method, a mixed concentration of the previous steel and the subsequent steel of a strand during casting was calculated by using operation data, such as a change in ladle weight, a change in tundish weight, and casting speed, of the previous performed operation as disclosed in Korean Patent No. 10-0419886. A mixed portion was determined by using the mixed concentration calculated from hydrodynamic principles and was cut off at both ends thereof. However, with respect to the above method of determining the mixed portion, the mixed concentration and the mixed portion were predicted without consideration of each position in the cross-section of the strand, i.e., surface and center. Thus, since reliability or accuracy of the prediction of the mixed portion is low, there have still been occasions in which at least a portion of the mixed portion is mixed in the product and delivered to client companies.

DISCLOSURE OF THE INVENTION

TECHNICAL PROBLEM

[0007] The present disclosure provides a method of continuous casting heterogeneous steels which may predict and automatically cut off a mixed portion of a strand which is produced by mixing previous steel and subsequent steel in a method of continuous casting different steels.

[0008] The present disclosure also provides a continuous casting method which may prevent product failure due to the mixed portion, which is caused by the continuous casting of heterogeneous steels, by calculating the position of the mixed portion of the strand to improve the accuracy of the prediction of the position and length of the mixed portion.

TECHNICAL SOLUTION

[0009] In accordance with an exemplary embodiment, a method of continuous casting heterogeneous steels includes: obtaining dimensionless relative concentrations of subsequent steel to previous steel respectively at surface and inside of a continuous cast strand in real time; calculating positions in a longitudinal direction of the strand having the dimensionless relative concentrations of the surface and the inside obtained in real time; predicting a mixed portion in the strand by respectively comparing the obtained dimensionless relative concentrations of the surface and the inside with reference concentrations; and cutting off the predicted mixed portion.

[0010] The positions of the strand, from which the dimensionless relative concentrations are obtained, may be a surface and a center in a height direction of the strand.

[0011] In accordance with another exemplary embodiment, a method of continuous casting heterogeneous steels includes: obtaining dimensionless relative concentrations of subsequent steel to previous steel respectively at a plurality of positions in a height direction of a strand solidified and continuous cast from a mold in real time by using relative amounts of the previous steel and the subsequent steel in a tundish and relative amounts of the previous steel and the subsequent steel in the mold; calculating positions in a longitudinal direction of the strand having the dimensionless relative concentrations obtained in real time; predicting a mixed portion in the strand by respectively comparing the obtained dimensionless relative concentrations with reference concentrations; and cutting off the predicted mixed portion.

[0012] The plurality of positions in the height direction of the strand, from which the dimensionless relative concentrations are obtained, may include a surface and a center of the strand.

[0013] The method may further include setting the reference concentrations, before the obtaining of the dimensionless relative concentrations of the subsequent steel to the previous steel in the continuous cast strand in real time, wherein the setting of the reference concentrations may include: setting a lowermost limit concentration among upper limit concentrations of each component of the previous steel as a first reference concentration; and setting an uppermost limit concentration among lower limit concentrations of each component of the subsequent steel as a second reference concentration.

[0014] The setting of the first reference concentration and the second reference concentration may include: calculating concentrations of the components of the previous steel as lower limit dimensionless concentrations and upper limit dimensionless concentrations; setting a lowermost limit dimensionless concentration among the upper limit dimensionless concentrations of the each component of the previous steel as the first reference concentration; calculating concentrations of the components of the subsequent steel as lower limit dimensionless concentrations and upper limit dimensionless concentrations; and setting an uppermost limit dimensionless concentration among the lower limit dimensionless concentrations of the each component of the subsequent steel as the second reference concentration.

[0015] The calculating of the concentrations of the each component of the previous steel as the lower limit dimensionless concentrations and the upper limit dimensionless concentrations may include: substituting a lower limit dimensionless concentration value of the previous steel with an upper limit dimensionless concentration value of the previous steel and substituting the upper limit dimensionless concentration value of the previous steel with the lower limit dimensionless concentration value of the previous steel when the lower limit dimensionless concentration of the previous steel is greater than the upper limit dimensionless concentration of the previous steel; and the calculating of the concentrations of the each component of the subsequent steel as the lower limit dimensionless concentrations and the upper limit dimensionless concentrations may include substituting a lower limit dimensionless concentration value of the subsequent steel with an upper limit dimensionless concentration value of the subsequent steel and substituting the upper limit dimensionless concentration value of the subsequent steel with the lower limit dimensionless concentration value of the subsequent steel when the lower limit dimensionless concentration of the subsequent steel is greater than the upper limit dimensionless concentration of the subsequent steel.

[0016] The strand may be determined to be in a mixed state when at least one dimensionless relative concentration of the obtained dimensionless relative concentrations of the surface and the center is deviated from the reference concentration, and a position in the longitudinal direction of the strand, in which at least one dimensionless relative concentration of the obtained dimensionless relative concentrations of the surface and the center is deviated from the reference concentration, may be determined as the mixed portion.

[0017] A position in the longitudinal direction of the strand, in which the obtained dimensionless relative concentration of the center reaches the reference concentration, may be determined as a starting point of the mixed portion, and a position in the longitudinal direction of the strand, in which the obtained dimensionless relative concentration of the surface reaches the reference concentration, may be determined as an end point of the mixed portion.

[0018] The method may further include: receiving data of a residual amount of molten steel in the tundish, casting speed, and concentrations of each of the previous steel and the subsequent steel on-line and storing the data; and detecting a subsequent ladle opening signal, before the obtaining of the dimensionless relative concentrations of the subsequent steel to the previous steel.

[0019] The method may further include: obtaining dimensionless relative concentrations of each of the surface and the center of the strand in real time from a time of detecting the subsequent ladle opening signal, and counting a dimensionless concentration acquisition time from the time of detecting the subsequent ladle opening signal to be compared with a reference time in real time; comparing the obtained dimensionless relative concentration of the center with the first reference concentration and comparing the obtained dimensionless relative concentration of the surface with the second reference concentration when the dimensionless concentration acquisition time is the reference time or less; and terminating the acquisition of the dimensionless relative concentrations of each of the surface and the center of the strand when the concentration acquisition time is greater than the reference time.

[0020] The method may further include determining whether or not a type between the previous steel and the subsequent steel is a type that is included in a preset heterogeneous steel cut-off table; cutting the strand to a cut-off length of the corresponding heterogeneous steel type when the type between the previous steel and the subsequent steel subjected to a current operation is the type that is included in the preset heterogeneous steel cut-off table; and cutting the strand to a preset predetermined cut-off length when the type between the previous steel and the subsequent steel subjected to the current operation is not included in the preset heterogeneous steel cut-off table, after the terminating of the acquisition of the dimensionless relative concentrations of each of the surface and the center of the strand.

[0021] The detecting of the subsequent ladle opening signal may include: sending a virtual ladle opening signal; detecting a weight of the tundish in real time, in milliseconds (ms) from a time when the virtual ladle opening signal is sent; calculating the weight of the tundish detected in milliseconds (ms) as an average weight of the tundish at predetermined time intervals in seconds (s); and setting a time of opening the subsequent ladle using a time of continuously increasing the average weight of the tundish.

[0022] When $W_{td}(t)$ is a weight of a residual-steel amount in the tundish at a current time and $W_{dt}(t-\Delta t)$ is a weight of a residual-steel amount in the tundish at an earlier time, $t-2^*\Delta t$ may be determined as the time of opening the subsequent ladle when both of $W_{td}(t) - W_{td}(t-\Delta t)$ and $W_{td}(t) - W_{td}(t-2^*\Delta t)$ are greater than or equal to "0", the dimensionless relative concentrations of each of the surface and the center of the strand may be obtained from $t-2^*\Delta t$, and the residual-steel amount in the tundish and the casting speed may be stored from $t-4^*\Delta t$.

[0023] The obtaining of the dimensionless relative concentrations of the subsequent steel to the previous steel at the surface and the center of the strand may include: calculating an inlet volumetric flow (Q_{td-in}) of the subsequent steel in the tundish; calculating an average dimensionless relative concentration ($C_{td-ave}(t+\Delta t)$) of the molten steel in the tundish at a current time using the inlet volumetric flow (Q_{td-in}) of the subsequent steel in the tundish; calculating a dimensionless relative concentration ($C_{td-out}(t+\Delta t)$) of the molten steel discharged from the tundish at a current time using the average dimensionless relative concentration ($C_{td-ave}(t+\Delta t)$) of the molten steel in the tundish at a current time; calculating an average dimensionless relative concentration ($C_{md-aver}(t+\Delta t)$) of the molten steel in the mold at a current time using the dimensionless relative concentration ($C_{td-out}(t+\Delta t)$) of the molten steel discharged from the tundish at a current time; and calculating a dimensionless relative concentration ($C_{md-out}(t+\Delta t)$) of the strand discharged from the mold at a current time using the average dimensionless relative concentration ($C_{md-aver}(t+\Delta t)$) of the molten steel in the mold at a current time and a dimensionless relative concentration ($C_{md-in}(t+\Delta t)$) of the molten steel introduced into the mold at a current time.

[0024] The inlet volumetric flow (Q_{td-in}) of the subsequent steel in the tundish may be calculated by Equation 5,

[Equation 5]

$$Q_{td-in} = \frac{W_{td}(t+\Delta t) - W_{td}(t)}{\Delta t \times \rho_L} + Q_{td-out}$$

wherein $W_{td}(t)$ is a total weight of the molten steel in the tundish at an earlier time, $W_{td}(t+\Delta t)$ is a total weight of the molten steel in the tundish at a current time, Q_{td-out} is a volumetric flow of the molten steel discharged from the tundish, and ρ_L is liquid density of the molten steel,

[0025] the average concentration ($C_{td-ave}(t+\Delta t)$) of the molten steel in the tundish at a current time may be calculated by Equation 6,

[Equation 6]

$$C_{td-ave}(t+\Delta t) = \frac{W_{td}(t) \times C_{td-ave}(t) + Q_{td-in}(t) \times \Delta t \times \rho_L \times C_{td-in}(t)}{W_{td}(t+\Delta t)} - \frac{Q_{td-out}(t) \times \Delta t \times \rho_L \times C_{td-out}(t)}{W_{td}(t+\Delta t)}$$

wherein $C_{td\text{-}ave}(t)$ is an average dimensionless relative concentration of the molten steel in the tundish at an earlier time, $Q_{td\text{-}in}(t)$ is an inlet volumetric flow of the molten steel introduced into the tundish at an earlier time, $C_{td\text{-}in}(t)$ is an inlet concentration (dimensionless relative concentration) of the subsequent steel in the tundish at an earlier time, $Q_{td\text{-}out}(t)$ is a volumetric flow of the molten steel discharged from the tundish at an earlier time, $C_{td\text{-}out}(t)$ is a concentration (dimensionless relative concentration) of the molten steel discharged from the tundish at an earlier time, and ρ_L is liquid density of the molten steel,

[0026] the concentration (($C_{td\text{-}out}(t+\Delta t)$) of the molten steel discharged from the tundish at a current time may be calculated by Equation 7,

[Equation 7]

$$C_{td\text{-}out}(t+\Delta t)=f_{td}\times C_{td\text{-}ave}(t+\Delta t)+(1-f_{td})\times C_{td\text{-}in}(t+\Delta t)$$

wherein f_{td} is an interpolation and extrapolation factor of the tundish, $C_{td\text{-}ave}(t+\Delta t)$ is an average dimensionless relative concentration of the molten steel in the tundish at a current time, and $C_{td\text{-}in}(t+\Delta t)$ is a dimensionless relative concentration of the molten steel introduced into the tundish at a current time,

the average concentration ($C_{md\text{-}aver}(t+\Delta t)$) of the molten steel in the mold at a current time may be calculated by Equation 8,

[Equation 8]

$$C_{md\text{-}ave}(t+\Delta t)=\frac{W_{md}(t)\times C_{md\text{-}ave}(t)+Q_{md\text{-}in}(t)\times\Delta t\times\rho_L\times C_{md\text{-}in}(t)}{W_{md}(t+\Delta t)}-\frac{Q_{md\text{-}out}(t)\times\Delta t\times\rho_L\times C_{md\text{-}out}(t)}{W_{md}(t+\Delta t)}$$

wherein $W_{md}(t)$ is a total weight of the molten steel in the mold at an earlier time, $C_{md\text{-}aver}(t)$ is an average dimensionless relative concentration of the molten steel in the mold at an earlier time, $Q_{md\text{-}in}(t)$ is an inlet volumetric flow of the molten steel in the mold at an earlier time, $C_{md\text{-}in}(t)$ is an inlet concentration (dimensionless relative concentration) of the molten steel in the mold at an earlier time, $W_{md}(t+\Delta t)$ is a total weight of the molten steel in the mold at a current time, $Q_{md\text{-}out}(t)$ is a volumetric flow of the molten steel discharged from the mold, $C_{md\text{-}out}(t)$ is a dimensionless relative concentration of the strand discharged from the mold at an earlier time, and ρ_L is liquid density of the molten steel, and

the concentration ($C_{md\text{-}out}(t+\Delta t)$) of the strand discharged from the mold at a current time may be calculated by Equation 9,

[Equation 9]

$$C_{md\text{-}out}(t+\Delta t)=f_{md}\times C_{md\text{-}ave}(t+\Delta t)+(1-f_{md})\times C_{md\text{-}in}(t+\Delta t)$$

wherein f_{md} is an interpolation and extrapolation factor of the mold, $C_{md\text{-}aver}(t+\Delta t)$ is an average dimensionless relative concentration of the molten steel in the mold at a current time, and $C_{md\text{-}in}(t+\Delta t)$ is a dimensionless relative concentration of the molten steel introduced into the mold at a current time.

[0027] In the calculating of the dimensionless relative concentration of the center of the strand, 4 ± 2 may be applied to the interpolation and extrapolation factor (f_{td}) of Equation 7, and 0.7 ± 0.4 may be applied to the interpolation and extrapolation factor (f_{md}) of Equation 9 to calculate the dimensionless relative concentration ($C_{md\text{-}out\text{-}center}$) of the center of the strand.

[0028] In the calculating of the dimensionless relative concentration of the surface of the strand, 2.2 ± 0.6 may be applied to the interpolation and extrapolation factor (f_{td}) of Equation 7, and 0.5 ± 0.2 may be applied to the interpolation and extrapolation factor (f_{md}) of Equation 9 to calculate the dimensionless relative concentration ($C_{md\text{-}out\text{-}surface}$) of the surface of the strand.

[0029] A liquid density of the molten steel may be used as a density (ρ_L) value in Equations 5, 6, and 8, and a value of 7,000 kg/m^3 to 7,400 kg/m^3 may be used as the density of the molten steel.

[0030] The method may further include: setting a position of the strand in which the dimensionless relative concentration of the surface of the strand begins to be obtained; and setting a position of the strand in which the dimensionless relative concentration of the center of the strand begins to be obtained, wherein a position of the strand at the time of opening the subsequent ladle may be set as the position in which the dimensionless relative concentration of the surface of the strand begins to be obtained, and a position of -4±4 m from the position of the strand at the time of opening the subsequent ladle may be set as the position in which the dimensionless relative concentration of the center of the strand begins to be obtained.

[0031] In the calculating of the position in the longitudinal direction of the strand having the obtained dimensionless relative concentration of the surface, the position may be calculated by Equation 10 in which a volumetric flow ($Q_{md\text{-}out}$) of the molten steel discharged from the mold is divided by a product of a cross-sectional area (A_{md}) of the strand and solid density (ρ_s) of the molten steel,

[Equation 10]

$$L(t+\Delta t)=L(t)+\frac{Q_{md\text{-}out} \times \rho_l}{A_{md} \times \rho_s} \times \Delta t$$

wherein $Q_{md\text{-}out}$ is a volumetric flow of the molten steel discharged from the mold, A_{md} is a cross-sectional area of the strand, and ρ_s is solid density of the molten steel, wherein a value of 7,600 kg/m^3 to 8,000 kg/m^3 is used.

[0032] In the calculating of the position in the longitudinal direction of the strand having the obtained dimensionless relative concentration of the center, a position of -4±4 m from the position having the obtained dimensionless relative concentration of the surface may be set as the position having the dimensionless relative concentration of the center.

[0033] A region from a point of the strand, in which the real-time obtained dimensionless relative concentration of the center of the strand reaches the first reference concentration, to a point of the strand, in which the real-time obtained dimensionless relative concentration of the surface of the strand reaches the second reference concentration, may be predicted as the mixed portion.

[0034] The method may further include: setting the point of the strand, in which the real-time obtained dimensionless relative concentration of the center of the strand reaches the first reference concentration, as a first cut-off position; setting the point of the strand, in which the real-time obtained dimensionless relative concentration of the surface of the strand reaches the second reference concentration, as a second cut-off position; and cutting off the mixed portion by cutting the strand respectively at the first cut-off position and the second cut-off position.

[0035] The predicting of the mixed portion of the strand and the cutting off of the predicted mixed portion may be performed as an online process.

ADVANTAGEOUS EFFECTS

[0036] According to exemplary embodiments, dimensionless concentrations of each of surface and center of a strand are obtained, and a position and a length of a mixed portion are derived by using the dimensionless concentrations. That is, the mixed portion is not cut to a predetermined length regardless of heterogeneous steel operating conditions as in the related art, but the dimensionless concentrations of each of the surface and the center of the strand are obtained for each operation of heterogeneous steels, and positions of the strand having the obtained dimensionless concentrations are set to predict the position and the length of the mixed portion. Thus, since the accuracy of the prediction of the position and length of the mixed portion is improved, a decrease in profitability due to excessive cut-off of the mixed portion may be prevented and the shipment of defect products due to less cut-off of the mixed portion to client companies may be prevented.

BRIEF DESCRIPTION OF THE DRAWINGS

[0037]

FIG. 1 illustrates general continuous casting equipment;
FIG. 2 illustrate principal parts of the general continuous casting equipment for describing a process of manufacturing a strand or slab through supply and solidification processes of molten steel;
FIG. 3 is a flowchart sequentially illustrating a method of predicting a heterogeneous steel mixed portion of the strand according to an exemplary embodiment and a method of cutting the mixed portion by using the above method;
FIGS. 4 and 5 are flowcharts specifically illustrating a method of cutting the mixed portion in a continuous casting

method according to an exemplary embodiment;

FIG. 6 is a flowchart specifically illustrating a process of detecting a subsequent ladle opening signal according to an exemplary embodiment;

FIG. 7 is a flowchart illustrating a method of setting a first reference concentration and a second reference concentration for the prediction of the heterogeneous steel mixed portion of the strand as a method according to an exemplary embodiment;

FIG. 8 is a graph illustrating a dimensionless concentration for each component of previous steel and subsequent steel which is obtained by the method according to the exemplary embodiment;

FIG. 9 is a graph illustrating a dimensionless concentration distribution of chromium (Cr) in a vertical direction (section thickness) and a casting direction (longitudinal direction) of the strand manufactured by heterogeneous steel continuous casting;

FIG. 10 is images illustrating changes in concentration in a mold over time during a heterogeneous steel continuous casting operation;

FIG. 11 is the result of calculating a concentration distribution with respect to the longitudinal direction and cross-section of the strand after the completion of final solidification by only considering an effect of the mold without considering an effect of tundish during the heterogeneous steel continuous casting operation;

FIG. 12 is a flowchart illustrating a method of obtaining dimensionless concentrations of surface and center of the strand according to an exemplary embodiment;

FIG. 13 is a graph comparing dimensionless concentration data of the surface and the center of the strand obtained according to the exemplary embodiment with results of the measurement of actual components in the longitudinal direction of the cast strand;

FIG. 14 is a graph comparing data in which a mixed portion is predicted by the prediction method according to the exemplary embodiment and concentrations are measured by collecting the predicted mixed portion; and

FIG. 15 is a graph in which lengths of mixed portions are analyzed by the method of predicting a mixed portion according to the exemplary embodiment for 1 year.

MODE FOR CARRYING OUT THE INVENTION

[0038] Hereinafter, exemplary embodiments will be described in detail with reference to the accompanying drawings. The present invention may, however, be embodied in different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the present invention to those skilled in the art.

[0039] Hereinafter, a solidified object, which is solidified in a mold, drawn or discharged to the outside of the mold, and formed by extending in a casting direction, in a state before cut-off is denoted as "strand", and an object, in which the strand is cut to a predetermined length, is denoted as "slab".

[0040] FIG. 1 illustrates general continuous casting equipment. FIG. 2 illustrate principal parts of the general continuous casting equipment for describing a process of manufacturing a strand or slab through supply and solidification processes of molten steel.

[0041] Referring to FIGS. 1 and 2, the continuous casting equipment includes ladles 100: 110 and 120 which accommodate refined molten steel and are movable, a tundish 200 configured to accommodate the molten steel supplied from the ladles 100: 110 and 120, a mold 300 which produces a strand S having a predetermined shape by receiving and solidifying the molten steel from the tundish 200, a nozzle 400 configured to inject the molten steel in the tundish 200 into the mold by having one end thereof connected to the tundish 200 and having at least a portion of the bottom thereof installed to be inserted into the mold 300, a plurality of rollers 500 configured to transport the strand S drawn from the mold 300 in a casting direction, a plurality of segments 600 configured to spray cooling water to the strand S being transported by the plurality of rollers 500, and a cutter 800 which cuts the strand S continuously produced from the mold 300 to a predetermined size to manufacture a slab 700 having a predetermined shape. Herein, a gas torch or a hydraulic shear may be used as the cutter 800.

[0042] The tundish 200 has an outlet for supplying the molten steel to the mold 300, wherein the outlet may be provided in plurality depending on continuous casting equipment and the mold 300 is provided in a number corresponding to the number of the outlets. Thus, with respect to continuous casting equipment having the plurality of molds 300, the strand S solidified and drawn from the mold 300 becomes a plurality.

[0043] In continuous casting of heterogeneous steels, molten steels of different steels having different components are accommodated in the first ladle 110 and the second ladle 120, and when any one ladle 110 or 120 completes the supply of the molten metal to the tundish 200, a ladle turret (not shown) rotates 180 degrees so as to shift the position of the one ladle 110 or 120 with respect to that of the other ladle 110 or 120. Accordingly, the molten steels of the different steels may be alternatinlgy supplied to the tundish. For example, casting is first performed by supplying the molten steel contained in the first ladle 110 to the tundish 200, and the molten steel of the second ladle 120 is supplied to the tundish

200 at the end of the casting and cast so that the heterogeneous steels are continuously cast.

[0044] In the continuous casting of the heterogeneous steels, since the molten steel of the steel currently being cast and being at the end of the operation (hereinafter, referred to as "previous steel") and the molten steel of the steel subsequently introduced (hereinafter, referred to as "subsequent steel") are mixed in the tundish 200 and the mold 300, a mixed portion, in which the previous steel and the subsequent steel are mixed and solidified, is generated in the strand S.

[0045] Thus, in the continuous casting of the heterogeneous steels, the present disclosure provides a method of continuous casting heterogeneous steels which may improve the accuracy of the prediction of the mixed portion and may automatically cut off the mixed portion by obtaining the concentration of the strand S in real time through an online system, calculating a position of the strand S having the obtained concentration, and predicting a position of the mixed portion in real time by using the calculated position.

[0046] FIG. 3 is a flowchart sequentially illustrating a method of predicting a heterogeneous steel mixed portion of the strand according to an exemplary embodiment and a method of cutting the mixed portion by using the above method. FIGS. 4 and 5 are flowcharts specifically illustrating a method of cutting the mixed portion in a continuous casting method according to an exemplary embodiment, and FIGS. 4 and 5 include the method of predicting a mixed portion and the method of cutting the mixed portion of FIG. 3.

[0047] Hereinafter, the method of cutting the mixed portion of the strand during the continuous casting of heterogeneous steels according to the exemplary embodiment will be described with reference to FIGS. 3 to 5. In this case, in continuous casting equipment having the plurality of strands which are solidified and drawn from the plurality of molds, since uniform molten steel is supplied to each strand by a flow control device in the tundish, e.g., a dam or a weir, the method of cutting the mixed portion is equally applied to each strand. Therefore, a case of applying the method to the single strand will be described.

[0048] Referring to FIG. 3, the method of predicting a heterogeneous steel mixed portion of the strand according to the exemplary embodiment includes the processes of: storing process variables or process data for continuous casting of heterogeneous steels (S100), detecting a signal of opening a ladle (hereinafter referred to as "subsequent ladle") containing subsequent steel (S200), setting a first reference concentration and a second reference concentration for predicting a heterogeneous steel mixed portion of a strand solidified and drawn from a mold (S300), obtaining dimensionless relative concentrations of the subsequent steel to previous steel at surface and inside of the strand in real time and calculating positions in a longitudinal direction of the strand having the dimensionless relative concentrations at the surface and the inside obtained in real time (S400), comparing the obtained dimensionless relative concentration of the inside of the strand with the first reference concentration in real time and comparing the obtained dimensionless relative concentration of the surface of the strand with the second reference concentration in real time (S600), predicting a mixed portion in the strand according to a comparison result between the obtained dimensionless relative concentrations of each of the surface and the inside and the first and second reference concentrations (S700), and cutting off the predicted mixed portion (S1100).

[0049] Herein, the surface and the inside of the strand may be surface and inside in a longitudinal direction (i.e., left and right direction) of the strand or in a vertical direction (or height direction) of the strand which crosses the casting direction, the inside may be the center in the vertical direction (or height direction) of the strand, and the surface may be any one of a top surface and a bottom surface of the strand.

[0050] Also, since the dimensionless relative concentration of the subsequent steel to the previous steel is a degree or amount in which the subsequent steel is mixed with respect to the previous steel, the dimensionless relative concentration, in other words, may be a degree in which the previous steel and the subsequent steel are mixed, i.e., "mixed concentration".

[0051] A dimensionless concentration represents a typical concentration value as a dimensionless ratio or dimensionless value, wherein the dimensionless concentration is a concentration represented by a value of 0 or more or 1 or less. Thus, the dimensionless relative concentration of the subsequent steel to the previous steel may also be represented by a value of 0 or more or 1 or less. A dimensionless concentration of the previous steel is defined as 0 and a dimensionless concentration of the subsequent steel is defined as 1. For example, in a case in which the dimensionless relative concentration is 0, it denotes a case in which an amount of the subsequent steel in the molten steel or the strand is 0%, i.e., a case in which there is no inflow of the subsequent steel. In contrast, in a case in which the dimensionless relative concentration is 1, it denotes a case in which the amount of the subsequent steel in the molten steel or the strand is 100%. For example, in a case in which the dimensionless relative concentration is 0.4, it denotes that the previous steel and the subsequent steel in the molten steel or the strand are mixed in a ratio of 60% to 40%.

[0052] The first reference concentration and the second reference concentration, which are compared with the dimensionless relative concentrations of each of the center and the surface of the strand obtained in real time, are dimensionless concentration values.

[0053] In the method of predicting and cutting a heterogeneous mixed portion according to the exemplary embodiment illustrated in FIG. 3, the method of predicting and cutting a heterogeneous mixed portion as described in FIG. 3 may or may not be used depending on acquisition time of the dimensionless relative concentrations of each of the surface and the center of the strand calculated from a time of opening of the subsequent ladle.

[0054] In other words, in a case in which the concentration acquisition time, in which the dimensionless relative concentrations of each of the surface and the center of the strand are obtained, is less than a reference time, a subsequent process is performed in which a mixed portion is predicted by comparing the obtained dimensionless concentrations of each of the center and the surface with the first and second reference concentrations. In contrast, in a case in which the concentration acquisition elapsed time of the surface and the center of the strand is greater than the reference time, the process of obtaining the concentration of each of the surface and the center is terminated. The mixed portion is cut off according to a data table, in which cut-off lengths of the mixed portion, which are preset according to types of the previous steel and the subsequent steel, are datafied, or the mixed portion is cut to a predetermined length which is preset regardless of the types of the previous steel and the subsequent steel.

[0055] FIGS. 4 and 5 are flowcharts which include a series of processes, in which the mixed portion is cut off by automatically predicting the position of the mixed portion according to the above-described dimensionless relative concentration acquisition time of each of the surface and the center of the strand, or the mixed portion is cut off by using the mixed portion cut-off length data table which is preset according to the combination of heterogeneous steels, or the mixed portion is cut to a predetermined length.

[0056] Referring to FIGS. 4 and 5, the method of continuous casting heterogeneous steels according to the exemplary embodiment includes the processes of: storing process data according to continuous casting of heterogeneous steels (S100), detecting a subsequent ladle opening signal (S200), setting a first reference concentration and a second reference concentration for predicting a heterogeneous steel mixed portion of a strand solidified and drawn from a mold (S300), obtaining dimensionless relative concentrations of each of surface and center of the strand in real time to calculate positions of the strand having the dimensionless relative concentrations of each of the surface and the center obtained at a current time (S400), and comparing dimensionless relative concentration acquisition time of the surface and the center of the strand with a reference time (S500).

[0057] In the above description, after the detecting of the subsequent ladle opening signal (S200), the setting of the first reference concentration and the second reference concentration for predicting the heterogeneous steel mixed portion of the strand solidified and drawn from the mold (S300) is performed. However, the exemplary embodiment of the present disclosure is not limited thereto, and a sequence of the detecting of the subsequent ladle opening signal (S200) and the setting of the first reference concentration and the second reference concentration for predicting the heterogeneous steel mixed portion of the strand solidified and drawn from the mold (S300) may be changed.

[0058] In addition, in a case in which the dimensionless relative concentration acquisition time of the surface and the center of the strand is the reference time or less (YES), the method of continuous casting heterogeneous steels according to the exemplary embodiment includes the processes of: comparing the obtained dimensionless relative concentration of the center of the strand with the first reference concentration in real time and comparing the obtained dimensionless relative concentration of the surface of the strand with the second reference concentration in real time (S600), predicting and determining a position of the mixed portion of the strand according to a comparison result between the obtained dimensionless relative concentrations of the surface and the center and the first and second reference concentrations (S700), and cutting off the predicted mixed portion (S1100).

[0059] Also, in a case in which the dimensionless relative concentration acquisition time of the surface and the center of the strand is greater than the reference time (NO), the method includes the processes of: terminating the acquisition of the dimensionless relative concentration of each of the surface and the center of the strand (S800), determining whether or not types of heterogeneous steels subjected to a current operation, i.e., the previous steel and the subsequent steel, are types that are included in a preset mixed portion cut-off length table (S900), cutting the mixed portion to a corresponding length by searching a type corresponding to a combination of the previous steel and the subsequent steel subjected to the operation when the combination of the previous steel and the subsequent steel subjected to the current operation is a type that is included in the preset cut-off length table (YES) (S1200), and cutting the mixed portion to a predetermined length, e.g., a maximum length when the combination of the previous steel and the subsequent steel subjected to the current operation is a type that is not included in the preset cut-off length table (NO) (S1300).

[0060] Hereinafter, each process of the continuous casting method according to the exemplary embodiment will be described in detail with reference to FIGS. 6 to 14.

[0061] FIG. 6 is a flowchart specifically illustrating a process of detecting a subsequent ladle opening signal according to an exemplary embodiment. FIG. 7 is a flowchart illustrating a method of setting the first reference concentration and the second reference concentration for the prediction of the heterogeneous steel mixed portion of the strand as a method according to an exemplary embodiment. FIG. 8 is a graph illustrating a dimensionless concentration for each component of previous steel and subsequent steel which is obtained by the method according to the exemplary embodiment. FIG. 9 is a graph illustrating a dimensionless concentration distribution of chromium (Cr) in the vertical direction (section thickness) and the casting direction (longitudinal direction) of the strand manufactured by heterogeneous steel continuous casting. FIG. 10 is images illustrating changes in concentration in the mold over time during a heterogeneous steel continuous casting operation. FIG. 11 is the result of calculating a concentration distribution with respect to the longitudinal direction and cross-section of the strand after the completion of final solidification by only considering an effect of the mold without considering an effect of the tundish during the heterogeneous steel continuous casting operation. FIG. 12 is a flowchart illustrating a method of obtaining dimensionless concentrations of the surface and the center of the strand according to an exemplary embodiment. FIG. 13 is a graph comparing dimensionless concentration data of the surface and the center of the strand obtained according to the exemplary embodiment with results of the measurement of actual components in the longitudinal direction of the cast strand. FIG. 14 is a graph comparing data in which the mixed portion is predicted by the prediction method according to the exemplary embodiment and concentrations are measured by collecting the predicted mixed portion.

[0062] In the storing of the heterogeneous steel continuous casting process data (S100), information, such as casting conditions and components of the heterogeneous steels, as variable data for the prediction of the mixed portion of the strand in the heterogeneous steel operation, is stored. That is, a residual amount of the molten steel in the tundish, casting speed, concentrations of components of the molten steel subjected to the current operation (hereinafter, referred to as "previous steel"), and concentrations of components of the molten steel subsequently supplied to the tundish (hereinafter, referred to as "subsequent steel") are stored. These process data may be initialized for each operation of the heterogeneous steels to be newly set and stored. Also, in the case that the plurality of strands is drawn from the continuous casting equipment, a casting speed for each strand is stored.

[0063] In an exemplary embodiment, the dimensionless relative concentration of the strand is obtained from the time of opening the subsequent ladle. Thus, there is a need to accurately detect a signal of opening the ladle in which the subsequent steel is stored. Referring to FIG. 6, the detecting of the subsequent ladle opening signal (S200) includes the processes of: sending a virtual subsequent ladle opening signal (S210), detecting a weight of the tundish in real time, in milliseconds (ms) from a time when the virtual subsequent ladle opening signal is sent (S220), calculating the weight of the tundish detected in milliseconds (ms) as an average weight of the tundish in second (s) intervals (S230), determining whether or not the average weight of the tundish calculated over time is continuously increased by receiving data of the average weight of the tundish in real time (S240), and setting a time of continuously increasing the average weight of the tundish as a time of opening the subsequent ladle (S250).

[0064] Typically, in the detection of the subsequent ladle opening signal, when a slide gate of the subsequent ladle was opened at a predetermined opening ratio or more, for example, 100%, the signal was received and detected as the subsequent ladle opening signal. However, a case frequently occurred in which the molten steel was not discharged even if the slide gate was opened because an outlet of the subsequent ladle was clogged. Thus, since the subsequent ladle opening signal was detected by only sensing an operation of the slide gate even if the molten steel was not discharged from the ladle, its accuracy may be low.

[0065] Typically, in order to address the above limitation in the detection of the subsequent ladle opening signal for the prediction of the mixed portion, the weight of the tundish was measured according to the time using a sensor for detecting the weight of the tundish, wherein the weight of the tundish was measured at very short time intervals in milliseconds (ms). In a case in which the weight of the tundish is continuously increased when a change in the weight of the tundish measured in real time, in milliseconds (ms) is analyzed, a programmable logic system (PLC) sends a signal that the subsequent ladle is opened. However, hunting of the weight of the tundish, which was measured at very short time intervals, i.e., in milliseconds (ms), may occur due to the sensitivity of the sensor. Accordingly, a case frequently occurred in which the PLC sent the subsequent ladle opening signal even in a situation in which the subsequent ladle is not actually opened. In order to address this limitation, the PLC was allowed to send the subsequent ladle opening signal at a time when the weight of the tundish at a time of continuous increase in the weight was again sensed after the weight of the tundish was continuously increased. However, since the opening signal was sent when the weight of the tundish at the time of continuous increase in the weight was again sensed, a case frequently occurred in which the ladle opening signal was delayed and sent unlike a real case. In order to address the delay of the opening signal, data for 10 minutes before the time when the weight of the tundish at the time of continuous increase in the weight was again sensed were searched and an operation of setting a time when the weight of the tundish was a minimum was again performed. However, such a method, as a follow-up method, has a limitation in that the subsequent ladle opening signal may not be detected in real time. Thus, the subsequent ladle opening signal may still be delayed or may not be correct, and this becomes a cause of reducing the accuracy of the prediction of the mixed portion.

[0066] Therefore, in order to accurately detect the subsequent ladle opening signal during the continuous casting operation of heterogeneous steels in the present disclosure, the PLC sends a virtual subsequent ladle opening signal according to operating conditions of heterogeneous steels, for example, when the casting speed and the residual amount of the molten steel are reduced and the casting speed and the residual-steel amount in the tundish are predetermined values or less (S210). Thereafter, the weight of the tundish is measured in milliseconds (ms), e.g., 200 ms, from a time when the virtual subsequent ladle opening signal is sent (S220). Subsequently, the weight of the tundish measured in milliseconds (ms) is calculated as an average weight of the tundish in seconds (s), for example, at predetermined time intervals of 1 second or 2 second (S230), and the calculated average weight of the tundish is analyzed in real time to determine whether or not the weight of the tundish is continuously increased (S240). That is, if they are described by equations, when "W_{td}" is a weight of the residual-steel amount in the tundish, "t" is a current time, and "t-Δ t" is an earlier time, t-2*Δ t is determined as the time of opening the subsequent ladle when both of W_{td}(t) - W_{td}(t-Δ t) and W_{td}(t) - W_{td}(t-2*Δ t) are greater than or equal to "0", and thus, a subsequent ladle opening signal is sent. A dimensionless relative concentration of each of the surface and the center of the strand is calculated from t-2*Δ t, and, for this purpose, the residual-steel amount in the tundish and the casting speed are stored from t-4*Δ t so as to enable the prediction of the mixed portion in real time.

[0067] The first reference concentration and the second reference concentration, which are compared with the dimensionless relative concentration of the center and the dimensionless relative concentration of the surface of the strand for the prediction of the mixed portion of heterogeneous steels, are dimensionless concentration values. Hereinafter, a method of calculating the first and second reference concentrations according to an exemplary embodiment will be described with reference to FIG. 7.

[0068] Referring to FIG. 7, a method of setting the first reference concentration and the second reference concentration for the prediction of the heterogeneous steel mixed portion of the strand according to an exemplary embodiment includes the processes of: receiving concentration data of all components of each of the previous steel and the subsequent steel (S310a and S310b), calculating a lower limit dimensionless concentration and an upper limit dimensionless concentration of each component of the previous steel (S320a), calculating a lower limit dimensionless concentration and an upper limit dimensionless concentration of each component of the subsequent steel (S320b), setting a lowermost limit dimensionless concentration value among upper limit dimensionless concentration values of each component of the previous steel as the first reference concentration (S330a), and setting an uppermost limit dimensionless concentration value among lower limit dimensionless concentration values of each component of the subsequent steel as the second reference concentration (S330b).

[0069] That is, the lower limit dimensionless concentration of each component of the previous steel is calculated by Equation 1, and the upper limit dimensionless concentration of each component of the previous steel is calculated by Equation 2. Also, the lower limit dimensionless concentration of each component of the subsequent steel is calculated by Equation 3, and the upper limit dimensionless concentration of each component of the subsequent steel is calculated by Equation 4.

[Equation 1]

$$\text{Lower limit dimensionless concentration of previous steel} = \frac{\text{lower limit concentration of previous steel design specifications} - \text{previous steel concentration}}{\text{subsequent steel concentration} - \text{previous steel concentration}}$$

[Equation 2]

$$\text{Upper limit dimensionless concentration of previous steel} = \frac{\text{upper limit concentration of previous steel design specifications} - \text{previous steel concentration}}{\text{subsequent steel concentration} - \text{previous steel concentration}}$$

[Equation 3]

$$\text{Lower limit dimensionless concentration of subsequent steel} = \frac{\text{lower limit concentration of subsequent steel design specifications} - \text{previous steel concentration}}{\text{subsequent steel concentration} - \text{previous steel concentration}}$$

[Equation 4]

$$\text{Upper limit dimensionless concentration of subsequent steel} = \frac{\text{upper limit concentration of subsequent steel design specifications} - \text{previous steel concentration}}{\text{subsequent steel concentration} - \text{previous steel concentration}}$$

[0070] In Equations 1 to 4, during the calculation of the dimensionless concentration for each component concentration, in a case in which the lower limit dimensionless concentration of the previous steel is greater than the upper limit dimensionless concentration of the previous steel, the lower limit dimensionless concentration value of the previous steel is substituted with the upper limit dimensionless concentration value of the previous steel and the upper limit dimensionless concentration value of the previous steel is substituted with the lower limit dimensionless concentration value of the previous steel. Also, in a case in which the lower limit dimensionless concentration of the subsequent steel is greater than the upper limit dimensionless concentration of the subsequent steel, the lower limit dimensionless concentration value of the subsequent steel is substituted with the upper limit dimensionless concentration value of the subsequent steel and the upper limit dimensionless concentration value of the subsequent steel is substituted with the lower limit dimensionless concentration value of the subsequent steel in the same manner. This is applied when the component concentration of the previous steel is higher than the component concentration of the subsequent steel.

[0071] For example, in a case in which a carbon (C) concentration of the previous steel is 0.4 wt% (0.38 wt% to 0.42 wt%), and a C concentration of the subsequent steel is 0.2 wt% (0.18 wt% to 0.22 wt%), a C dimensionless concentration of the previous steel becomes 0 (0.1 to -0.1) when dimensionless transformation is performed. That is, since the upper limit dimensionless concentration of the previous steel becomes -0.1 and the lower limit dimensionless concentration of the previous steel becomes 0.1, these values are substituted with each other.

[0072] In general, there is a design specification concentration for each component depending on the type of steel to be manufactured. That is, conditions of the steel to be manufacture are satisfied only when the concentration of each component is included in a design specification concentration range, and the design specification concentration range includes lowermost and uppermost limit values for each component and a value between the lowermost and uppermost limit values. Thus, in the continuous casting of heterogeneous steels, there is a design specification concentration range for each component of the previous steel, and there is a design specification concentration range for each component of the subsequent steel.

[0073] Also, the concentration of each component of the previous steel denotes a concentration of each component of molten steel first cast in a current heterogeneous steel operation and is a concentration determined through a refining process before the molten steel is supplied to the tundish, wherein it is a concentration value included in the design specification concentration range of the previous steel. Similarly, the concentration of each component of the subsequent steel denotes a concentration of each component of molten steel subsequently supplied and is also a concentration determined through the refining process before the molten steel is supplied to the tundish, wherein it is a concentration value included in the design specification concentration range of the subsequent steel.

[0074] In Equations 1 to 4, the lower limit and upper limit dimensionless concentrations of the previous steel and the lower limit and upper limit dimensionless concentrations of the subsequent steel are calculated by using the design specification lower limit concentration of the previous steel, the design specification upper limit concentration of the previous steel, the design specification lower limit concentration of the subsequent steel, the design specification upper limit concentration of the subsequent steel, the concentration of the previous steel, and the concentration of the subsequent steel as described above. The lowermost limit dimensionless concentration value among the upper limit dimensionless concentration values of each component of the previous steel is set as the first reference concentration, and the uppermost limit dimensionless concentration value among the lower limit dimensionless concentration values of each component of the subsequent steel is set as the second reference concentration. Also, in a subsequent process, the first reference concentration is a value compared with the dimensionless relative concentration of the center of the strand calculated in real time, and the second reference concentration is a value compared with the dimensionless relative concentration of the surface of the strand calculated in real time.

[0075] FIG. 8 is a graph illustrating the dimensionless concentration for each component of the previous steel and the subsequent steel which is calculated by the method according to the exemplary embodiment. For example, C, manganese (Mn), and Cr are included in each of the previous steel and the subsequent steel, and when lower limit dimensionless concentrations and upper limit dimensionless concentrations of C, Mn, and Cr components are calculated by the above-described Equations 1 to 4, the results are as illustrated in FIG. 8. Referring to FIG. 8, among the upper limit dimensionless concentrations of C, Mn, and Cr, the upper limit dimensionless concentration of Cr is lower than the upper limit dimensionless concentration of C or Mn. Thus, the upper limit dimensionless concentration of Cr is set as the first reference concentration. Among the lower limit dimensionless concentrations of C, Mn, and Cr, the lower limit dimensionless concentration of Cr is higher than the lower limit dimensionless concentration of C or Mn. Thus, the lower limit dimensionless concentration of Cr is set as the second reference concentration. Therefore, according to the example of FIG. 8, the first reference concentration, as a lowermost limit value of the dimensionless concentration for the prediction of the mixed portion, is 0.07, and the second reference concentration, as an uppermost limit value, is 0.95. In other words, the dimensionless concentration of the mixed portion is in a range of 0.07 or more to 0.95 or less, and a region from a point where the dimensionless relative concentration of the center of the strand calculated in real time is 0.07 to a point where the dimensionless relative concentration of the surface is 0.95 is predicted as the mixed portion.

[0076] The reason for the comparison of the lowermost limit dimensionless concentration value among the uppermost limit dimensionless concentration values of each component of the previous steel, which is set as the first reference concentration, with the dimensionless relative concentration of the center calculated in real time and the comparison of the uppermost limit dimensionless concentration value among the lowermost limit dimensionless concentration values of each component of the subsequent steel, which is set as the second reference concentration, with the dimensionless relative concentration of the surface calculated in real time is as follows.

[0077] During the continuous casting of heterogeneous steels, a concentration of one end of the mixed portion of the strand solidified by mixing the previous steel and the subsequent steel satisfies the design specification concentration of the previous steel, and the other end of the mixed portion satisfies the design specification concentration of the subsequent steel. A region between the one end and the other end of the mixed portion is outside the design specification concentration range of each of the previous steel and the subsequent steel.

[0078] Referring to FIG. 9, it may be understood that the concentration is changed along a vertical direction (cross-section thickness direction) and a casting direction (longitudinal direction) of the slab. The dimensionless relative concentrations of positions in the vertical direction of the strand, i.e., the surface and the center, have a different trend pattern. Specifically, mixing between the previous steel and the subsequent steel occurs in the surface of the strand after the time of opening the subsequent ladle. However, with respect to the center, the mixing occurs in the strand before the time of opening the subsequent ladle. The reason for this is that diffusion of the molten steel mixed and remixed through the tundish and the mold to the center of an unsolidified molten steel layer in the strand occurs due to a concentration gradient. That is, the mixing between the previous steel and the subsequent steel is started in the center of the strand earlier than the surface of the strand.

[0079] Thus, in the present disclosure, when the dimensionless relative concentration of the center of the strand obtained in real time reaches the lowermost limit dimensionless concentration value (i.e., the first reference concentration) among the upper limit dimensionless concentration values of each component of the previous steel or is deviated from the lowermost limit dimensionless concentration value (i.e., the first reference concentration), it is determined as a state in which the mixing is started, and in this case, a position in the longitudinal direction of the strand is determined as a first cut-off position. Also, when the dimensionless relative concentration of the surface of the strand calculated in real time reaches the uppermost limit dimensionless concentration value (i.e., the second reference concentration) among the lower limit dimensionless concentration values of each component of the subsequent steel or is deviated from the uppermost limit dimensionless concentration value (i.e., the second reference concentration), it is determined as a state in which the mixing is terminated, and in this case, a position of the strand is determined as a second cut-off position. In other words, the position in the longitudinal direction of the strand, in which the dimensionless relative concentration of the center is the lowermost limit dimensionless concentration among the upper limit dimensionless concentration values of each component of the previous steel, is a starting position of the mixed portion, and the position in the longitudinal direction of the strand, in which the dimensionless relative concentration of the surface is the uppermost limit dimensionless concentration among the lower limit dimensionless concentration values of each component of the subsequent steel, is an end position of the mixed portion. Thus, in the present disclosure, the lowermost limit dimensionless concentration among the upper limit dimensionless concentration values of each component of the previous steel is named as the first reference concentration and the first reference concentration is compared with the obtained dimensionless relative concentration of the center. The uppermost limit dimensionless concentration among the lower limit dimensionless concentration values of each component of the subsequent steel is named as the second reference concentration, and the second reference concentration is compared with the obtained dimensionless relative concentration of the surface to predict as the mixed portion in which heterogeneous steels are mixed. That is, the position in the longitudinal direction of the strand, in which the dimensionless relative concentration of the center obtained in real time reaches the first reference concentration, is determined as the first cut-off position, and the position in the longitudinal direction of the strand, in which the dimensionless relative concentration of the surface reaches the second reference concentration, is determined as the second cut-off position to cut off the mixed portion.

[0080] Typically, in the prediction of the mixed portion, the mixed portion was predicted without separate consideration of each cross-sectional position, i.e., surface and center, of the strand. That is, typically, a concentration of the strand was obtained under the assumption that concentrations of the surface and the center are the same at one position in the longitudinal direction of the strand. Accordingly, since accuracy of the position of the mixed portion or the prediction of the mixed portion was low, occasions frequently occurred in which the mixed portion was mixed in the product and delivered to client companies.

[0081] Thus, in the present disclosure, it is recognized that the concentrations of the surface and the center are different at one position in the longitudinal direction of the strand as described above, and the dimensionless relative concentrations of each of the surface and the center of the strand are respectively obtained during the continuous casting of heterogeneous steels to predict the mixed portion.

[0082] In a typical continuous casting operation of heterogeneous steels, when the subsequent steel is supplied to a tundish, the previous steel and the subsequent steel are mixed in the tundish, and, in this case, a portion of the mixed steel is discharged during a process of mixing the previous steel and the subsequent steel and the remainder is continuously remixed while being continuously recycled in the tundish. In addition, the molten steel mixed and remixed in the tundish is discharged into a mold through a submerged entry nozzle, wherein the molten steel discharged through the submerged entry nozzle has a turbulent flow. As a result, the mixed molten steel introduced into the mold from the tundish produces a recirculation flow in an upper region due to the turbulent flow of the molten steel in the mold, and accordingly, mixing and remixing phenomena repeatedly occur also in the mold and a concentration in the mold is changed in real time (see FIG. 10). Referring to FIG. 11, a mixed portion, in which the previous steel and the subsequent steel are mixed, is present in the strand which is solidified and drawn from the mold, and in a case in which a thickness of the slab is 0.4 m when considering only the mold mixing without consideration of the mixing in the tundish, a length of the mixed portion is approximately 4 m.

[0083] From the above descriptions of FIGS. 10 and 11, it may be understood that the mixing of the heterogeneous steels is performed in the mold as well as the tundish, and the mixed portion, in which the previous steel and the subsequent steel are mixed, is obtained in the strand by the mixing in the mold.

[0084] Typically, since the mixed portion was predicted by only considering the mixing in the tundish without consideration of the mixing in the mold, the accuracy of the position of the mixed portion or the prediction of the mixed portion was low, and thus, occasions frequently occurred in which at least a portion of the mixed portion was mixed in the product and delivered to client companies.

[0085] Thus, in the present disclosure, since the mixed portion is predicted and cut off by considering the mixing of the heterogeneous steels in the mold as well as the tundish, the accuracy of the cut-off of the mixed portion may be improved.

[0086] During the continuous casting of the heterogeneous steels, the calculating of the dimensionless relative concentrations of each of the surface and center in the strand and calculating the positions in the longitudinal direction of the strand having the corresponding dimensionless relative concentrations (S400) includes the processes of: obtaining the dimensionless relative concentrations of each of the surface and center of the strand in real time from a time of detecting the subsequent ladle opening signal (S410) and calculating the positions of the strand having the calculated concentrations of the surface and the center (S420).

[0087] For the calculating of the concentrations of the surface and center of the strand in real time from the time of detecting the subsequent ladle opening signal (S410), the calculation is performed in consideration of the mixing in the mold as described in the present disclosure, and thus, an equation (hereinafter, referring to "Equation 9") for calculating the concentrations of the surface and the center of the strand includes a concentration of the steel discharged from the mold. In the following equation, "t+Δ t" denotes a current time and "t" denotes an earlier time.

[0088] Hereinafter, a process of obtaining the concentrations of the surface and the center of the strand in real time from the time of detecting the subsequent ladle opening signal will be described. In an exemplary embodiment, the obtaining of the concentrations of the surface and the center of the strand is performed by calculating the concentrations according to the following equations. Thus, "the obtaining of the concentrations of the surface and the center of the strand" may be expressed, in other words, by "the calculating of the concentrations of the surface and the center of the strand".

[0089] In the physical aspect, a change in the amount of the molten steel introduced into the tundish may be expressed by a value in which a change in the weight of the tundish is divided by a change in time (Δ t) and liquid density of the molten steel. In an exemplary embodiment, an inlet volumetric flow ($Q_{td\text{-}in}$) of the subsequent steel in the tundish is first calculated by using the above-described physical concept of the change in the amount of the molten steel introduced into the tundish (S411).

[0090] In this case, the inlet volumetric flow ($Q_{td\text{-}in}$) of the subsequent steel in the tundish may be calculated by Equation 5 described below.

[Equation 5]

$$Q_{td\text{-}in} = \frac{W_{td}(t+\Delta t) - W_{td}(t)}{\Delta t \times \rho_L} + Q_{td\text{-}out}$$

where $W_{td}(t)$ is a total weight of the molten steel in the tundish at an earlier time, $W_{td}(t+\Delta t)$ is a total weight of the molten steel in the tundish at a current time, $Q_{td\text{-}out}$ is a volumetric flow of the molten steel discharged from the tundish, and ρ_L is liquid density of the molten steel.

[0091] The total weight ($W_{td}(t)$) of the molten steel in the tundish at an earlier time and the total weight ($W_{td}(t+\Delta t)$) of the molten steel in the tundish at a current time are measured in real time from a sensor disposed on an outer bottom of the tundish, and the volumetric flow ($Q_{td\text{-}out}$) of the molten steel discharged from the tundish is calculated as a sum of a product of a cross-sectional size of the mold and casting speed measured from a sensor disposed on one side of the strand. Also, since the molten steel is a liquid, a liquid density of the molten steel of 7,000 kg/m^3 to 7,400 kg/m^3 is used instead of a solid density of the molten steel of 7,600 kg/m^3 to 8,000 kg/m^3. Specifically, for example, a liquid density of the molten steel of approximately 7,200 kg/m^3 is used instead of a solid density of the molten steel of approximately 7,800 kg/m^3.

[0092] Thereafter, an average dimensionless relative concentration ($C_{td\text{-}ave}(t+\Delta\ t)$) of the molten steel in the tundish is calculated using the calculated inlet volumetric flow ($Q_{td\text{-}in}$) of the subsequent steel in the tundish (S412). A flow of the molten steel generated in the tundish may be classified into a primary flow and a secondary flow including a dead zone, and accordingly, the concentration of the molten steel may be locally different depending on the position of the molten steel in the tundish. However, in the present disclosure, for the purpose of the prediction of the concentration generated according to upper, lower, right, and left positions of the strand, it is assumed that the average dimensionless relative concentration of the molten steel in the tundish is represented by a specific value without consideration of the local flow, and the specific value is defined as the average dimensionless relative concentration of the molten steel in the tundish. In this case, the average dimensionless relative concentration ($C_{td\text{-}ave}(t+\Delta\ t)$) of the molten steel in the tundish may be calculated by Equation 6 below.

[Equation 6]

$$C_{td\text{-}ave}(t+\Delta t)=\frac{W_{td}(t)\times C_{td\text{-}ave}(t)+Q_{td\text{-}in}(t)\times\Delta t\times\rho_L\times C_{td\text{-}in}(t)}{W_{td}(t+\Delta t)}-\frac{Q_{td\text{-}out}(t)\times\Delta t\times\rho_L\times C_{td\text{-}out}(t)}{W_{td}(t+\Delta t)}$$

where $C_{td\text{-}ave}(t+\Delta\ t)$ is an average dimensionless relative concentration of the molten steel in the tundish at a current time, $W_{td}(t)$ is a total weight of the molten steel in the tundish at an earlier time, $C_{td\text{-}ave}(t)$ is an average dimensionless relative concentration of the molten steel in the tundish at an earlier time, $Q_{td\text{-}in}(t)$ is an inlet volumetric flow of the molten steel introduced into the tundish at an earlier time, $C_{td\text{-}in}(t)$ is an inlet concentration (dimensionless relative concentration) of the subsequent steel in the tundish at an earlier time, $Q_{td\text{-}out}(t)$ is a volumetric flow of the molten steel discharged from the tundish at an earlier time, $C_{td\text{-}out}(t)$ is a concentration (dimensionless relative concentration) of the molten steel discharged from the tundish at an earlier time, and ρ_L is liquid density of the molten steel.

[0093] Herein, a value calculated by Equation 5 as described above is used as the inlet volumetric flow ($Q_{td\text{-}in}$) of the subsequent steel in the tundish, the total weight ($W_{td}(t)$) of the molten steel in the tundish at an earlier time and the total weight ($W_{td}(t+\Delta\ t)$) of the molten steel in the tundish at a current time are respectively values measured in real time, i.e., at a predetermined time interval, from the sensor disposed in the tundish, the volumetric flow ($Q_{td\text{-}out}$) of the molten steel discharged from the tundish at a current time may be calculated as a sum of a product of the cross-sectional size of the mold and the casting speed measured from the sensor disposed on one side of the strand, and ρ_L is the liquid density of the molten steel, wherein a value of 7,000 kg/m^3 to 7,400 kg/m^3, for example, approximately 7,200 kg/m^3, is used.

[0094] In the supplying of the subsequent steel contained in the ladle to the tundish, since it is before the subsequent steel is supplied to the tundish and mixed, the concentration ($C_{td\text{-}in}(t)$) of the subsequent steel introduced into the tundish at an earlier time is always "1". Also, an initial value of the average dimensionless relative concentration ($C_{td\text{-}ave}(t)$) of the molten steel in the tundish at an earlier time and an initial value of the dimensionless relative concentration ($C_{td\text{-}out}(t)$) of the molten steel discharged from the tundish are set as 0 .

[0095] The average dimensionless relative concentration ($C_{td\text{-}ave}(t+\Delta\ t)$) of the molten steel in the tundish at a current time is calculated by using the initial values set as described above.

[0096] Next, a value calculated by Equation 6 is used as the average dimensionless relative concentration ($C_{td\text{-}ave}(t+\Delta\ t)$) of the molten steel in the tundish at a current time, and a value, which is calculated at a current time by Equation 7 to be described later, is used as a dimensionless relative concentration ($C_{td\text{-}out}(t+\Delta t)$) of the molten steel discharged from the tundish at a current time.

[0097] When the average dimensionless relative concentration ($C_{td\text{-}ave}(t+\Delta\ t)$) of the molten steel in the tundish at a current time is calculated, the dimensionless relative concentration ($C_{td\text{-}out}(t+\Delta t)$) of the molten steel discharged from the tundish at a current time is calculated using the average dimensionless relative concentration ($C_{td\text{-}ave}(t+\Delta\ t)$) (S413). In this case, in the present disclosure, the dimensionless relative concentration (($C_{td\text{-}out}(t+\Delta t)$) of the molten steel discharged from the tundish is calculated by the following Equation 7.

[Equation 7]

$$C_{td\text{-}out}(t+\Delta t)=f_{td}\times C_{td\text{-}ave}(t+\Delta t)+(1-f_{td})\times C_{td\text{-}in}(t+\Delta t)$$

where $C_{td\text{-}out}(t+\Delta t)$ is a dimensionless relative concentration of the molten steel discharged from the tundish at a current time, $C_{td\text{-}ave}(t+\Delta t)$ is an average dimensionless relative concentration of the molten steel in the tundish at a current time, and $C_{td\text{-}in}(t+\Delta t)$ is a dimensionless relative concentration of the molten steel introduced into the tundish at a current time. The average dimensionless relative concentration ($C_{td\text{-}ave}(t+\Delta t)$) of the molten steel in the tundish at a current time is calculated by Equation 6 and used as described above, and the dimensionless relative concentration ($C_{td\text{-}in}$) of the subsequent steel introduced into the tundish at a current time is 1. f_{td} is an interpolation and extrapolation factor, wherein different interpolation and extrapolation factors are respectively used for the calculation of the dimensionless relative concentration of the center of the strand and the dimensionless relative concentration of the surface of the strand. That is, an interpolation and extrapolation factor (f_{td_center}) used for the calculation of the concentration of the center of the strand is 4±2, and an interpolation and extrapolation factor ($f_{td\_surface}$) used for the calculation of the concentration of the surface of the strand is 2.2±0.6.

[0098] Subsequently, an average dimensionless relative concentration ($C_{md\text{-}aver}(t+\Delta t)$) of the molten steel in the mold at a current time is calculated using the dimensionless relative concentration (($C_{td\text{-}out}(t+\Delta t)$) of the molten steel discharged from the tundish at a current time (S414), and is calculated by Equation 8 in the present disclosure.

[Equation 8]

$$C_{md\text{-}ave}(t+\Delta t)=\frac{W_{md}(t)\times C_{md\text{-}ave}(t)+Q_{md\text{-}in}(t)\times\Delta t\times\rho_L\times C_{md\text{-}in}(t)}{W_{md}(t+\Delta t)}-\frac{Q_{md\text{-}out}(t)\times\Delta t\times\rho_L\times C_{md\text{-}out}(t)}{W_{md}(t+\Delta t)}$$

where $W_{md}(t)$ is a total weight of the molten steel in the mold at an earlier time, $C_{md\text{-}aver}(t)$ is an average dimensionless relative concentration of the molten steel in the mold at an earlier time, $Q_{md\text{-}in}(t)$ is an inlet volumetric flow of the molten steel in the mold at an earlier time, $C_{md\text{-}in}(t)$ is an inlet concentration (dimensionless relative concentration) of the molten steel in the mold at an earlier time, $W_{md}(t+\Delta t)$ is a total weight of the molten steel in the mold at a current time, $Q_{md\text{-}out}(t)$ is a volumetric flow of the molten steel discharged from the mold, $C_{md\text{-}out}(t)$ is a dimensionless relative concentration of the steel (i.e., strand) discharged from the mold at an earlier time, and ρ_L is liquid density of the molten steel, wherein the density is 7,000 kg/m^3 to 7,400 kg/m^3, for example, approximately 7,200 kg/m^3.

[0099] Herein, the total weight ($W_{md}(t+\Delta t)$) of the molten steel in the mold at a current time and the total weight ($W_{md}(t)$) of the molten steel in the mold at an earlier time may be calculated using length and cross-sectional area of the mold and the density of the molten metal. That is, the total weight may be calculated by an equation of "total weight (W_{md}) of the molten steel in the mold = (total length of the mold - length from the top of the mold to meniscus) × internal cross-sectional area of the mold × liquid density of the molten steel". Herein, the internal cross-sectional area of the mold is the same as the cross-sectional area of the strand. Also, a flow of the strand (or steel) discharged from the mold may be calculated as a total sum of a product of the internal cross-sectional area of the mold and the casting speed measured from the sensor disposed on one side of the strand. The dimensionless relative concentration ($C_{md\text{-}in}(t)$) of the subsequent steel introduced into the mold at an earlier time is always the same as the dimensionless relative concentration ($C_{td\text{-}out}(t)$) of the subsequent steel discharged from the tundish at an earlier time. Also, an initial value of the average dimensionless relative concentration ($C_{md\text{-}aver}(t)$) of the molten steel in the mold at an earlier time and an initial value of the dimensionless relative concentration ($C_{md\text{-}out}(t)$) of the molten steel discharged from the mold are set as 0.

[0100] The average dimensionless relative concentration ($C_{md\text{-}aver}(t)$) of the molten steel in the mold at a current time is calculated using the set initial values.

[0101] Next, a value calculated by Equation 8 is used as the average dimensionless relative concentration ($C_{md\text{-}aver}(t+\Delta t)$) of the molten steel in the mold at a current time, and a value, which is calculated at a current time by Equation 9 to be described later, is used as a dimensionless relative concentration ($C_{md\text{-}out}(t+\Delta t)$) of the molten steel discharged from the mold at a current time.

[0102] Thereafter, a dimensionless relative concentration ($C_{md\text{-}out}(t+\Delta t)$) of the steel (i.e., strand) discharged from the mold at a current time is calculated (S415). In the present disclosure, the dimensionless relative concentration ($C_{md\text{-}out}(t+\Delta t)$) of the steel (i.e., strand) discharged from the mold at a current time is calculated by the following Equation 9.

[Equation 9]

$$C_{md\text{-}out}(t+\triangle t)=f_{md}\times C_{md\text{-}ave}(t+\triangle t)+(1-f_{md})\times C_{md\text{-}in}(t+\triangle t)$$

where $C_{md\text{-}out}(t+\Delta t)$ is a dimensionless relative concentration of the steel (i.e., strand) discharged from the mold at a current time, $C_{md\text{-}aver}(t+\Delta t)$ is an average dimensionless relative concentration of the molten steel in the mold at a current time, and $C_{md\text{-}in}(t+\Delta t)$ is a dimensionless relative concentration of the molten steel introduced into the mold at a current time. Herein, the dimensionless relative concentration ($C_{md\text{-}out}(t+\Delta t)$) of the steel discharged from the mold at a current time is a dimensionless relative concentration of the strand solidified and discharged or drawn from the mold at a current time and is a value to be calculated by Equation 9. Also, a value calculated by the above-described Equation 8 is used as the average dimensionless relative concentration ($C_{md\text{-}aver}$ $(t+\Delta t)$) of the molten steel in the mold at a current time, and f_{md} is an interpolation and extrapolation factor, wherein different interpolation and extrapolation factors are respectively used for the calculation of the dimensionless relative concentration of the center of the strand and the dimensionless relative concentration of the surface of the strand. That is, an interpolation and extrapolation factor (f_{md_center}) used for the calculation of the dimensionless relative concentration of the center is 0.7 ± 0.4, and an interpolation and extrapolation factor ($f_{md\_surface}$) used for the calculation of the dimensionless relative concentration of the surface of the strand is 0.5 ± 0.2. Furthermore, the dimensionless relative concentration ($C_{md\text{-}in}(t+\Delta t)$) of the molten steel introduced into the mold at a current time is the dimensionless relative concentration ($C_{td\text{-}out}(t+\Delta t)$) of the steel discharged from the tundish at a current time, wherein a value calculated by the above-described Equation 7 is used. Since the molten steel discharged from the mold is mainly composed of liquid molten steel, a liquid density value of the molten steel of 7,000 kg/m^3 to 7,400 kg/m^3, for example, approximately 7,200 kg/m^3 is used.

[0103] The dimensionless relative concentrations of each of the surface and the center of the strand are obtained in real time during the heterogeneous steel operation by the above-described method, and the positions in the longitudinal direction (or casting direction) of the strand having the dimensionless relative concentrations of each of the surface and the center obtained in real time are then calculated (S420).

[0104] For this purpose, in the longitudinal direction (or casting direction) of the strand, a process of setting a position in which the dimensionless relative concentration of the surface of the strand begins to be obtained and a position in which the dimensionless relative concentration of the center of the strand begins to be obtained is first performed. As described above, the reason for this is that, during the continuous casting of heterogeneous steels, the mixed portion between the previous steel and the subsequent steel is present on the surface of the strand after the time of opening the subsequent ladle, but mixing occurs in the center of the strand before the time of opening the subsequent ladle. That is, the reason is that the diffusion of the molten steel mixed and remixed through the tundish and the mold to the center of the unsolidified molten steel layer in the strand occurs due to the concentration gradient. Accordingly, the mixing between the previous steel and the subsequent steel occurs in the center of the strand earlier than the surface of the strand, and, in general, the mixing in the center generally occurs at a position of -4 ± 4 m from a position of the strand at the time of detecting the subsequent ladle opening signal.

[0105] Thus, there is a need to set the position in which the concentration begins to be obtained, particularly, the position in which the concentration of the center begins to be obtained.

[0106] Accordingly, in the present disclosure, the position of the strand at the time of detecting the subsequent ladle opening signal is set as the position in which the dimensionless relative concentration of the surface of the strand begins to be measured. In addition, the position of -4 ± 4 m from the position of the strand at the time of detecting the subsequent ladle opening signal is set as the position in which the dimensionless relative concentration of the center of the strand begins to be obtained.

[0107] When the positions in which the dimensionless relative concentrations of each of the surface and the center of the strand begins to be obtained are set, the position of the strand having the calculated dimensionless relative concentration of the center of the strand at a current time and the position of the strand having the calculated dimensionless relative concentration of the surface of the strand at a current time are calculated (S420).

[0108] First, the position of the strand having the calculated dimensionless relative concentration of the surface may be obtained from a length value which is calculated by dividing a product of a mold discharge volumetric flow ($Q_{md\text{-}out}$) in the strand and liquid density of the molten steel by a product of a cross-sectional area (A_{md}) of the strand and solid density (ρ_s) of the molten steel. When this is expressed by an equation (hereinafter, referred to as "Equation 10"), the equation is as follows.

[Equation 10]

$$L(t+\Delta t)=L(t)+\frac{Q_{md\text{-}out} \times \rho_l}{A_{md} \times \rho_s} \times \Delta t$$

[0109] Herein, the reason for using the solid density (7,600 kg/m^3 to 8,000 kg/m^3) of the molten steel as a density value is that a shrinkage in the longitudinal direction due to the solidification of the liquid molten steel is considered.

[0110] The value calculated by Equation 10 is a length value, and a position of a point, which moves as much as the calculated length value based on a position of the meniscus of the strand, is the position of the strand having the corresponding concentration of the surface. In addition, the position of the strand having the calculated concentration of the center is a position of -4±4 m from the position of the strand having the concentration of the surface obtained at the same time.

[0111] Thus, in the present disclosure, the dimensionless relative concentration of the surface and the dimensionless relative concentration of the center of the strand are obtained by the above-described method, and the positions in the longitudinal direction of the strand having the obtained dimensionless relative concentrations of each of the surface and the center are calculated. In addition, calculation time is counted from a time of calculating the dimensionless relative concentration of each of the surface and the center of the strand, and the calculation time is compared with the reference time in real time (S500).

[0112] In the continuous casting operation, the strand drawn from the mold is transferred in the casting direction, i.e., a direction in which the cutter is disposed, as the casting time has elapsed. Accordingly, the mixed portion generated in the strand is gradually close to the cutter as the operation time has elapsed, and the prediction of the mixed portion must be ended before the mixed portion is disposed under the cutter. In other words, before the actual mixed portion is disposed under the cutter, the calculated dimensionless relative concentration of the center must reach the first reference concentration and the calculated dimensionless relative concentration of the surface must reach the second reference concentration. Thus, in an exemplary embodiment, a reference drawn time is set in consideration of the casting speed of heterogeneous steels, wherein the reference time is counted from the beginning of the calculation of the dimensionless relative concentration of each of the surface and the center, and is a time in which the mixed portion does not pass the cutter and reaches a predetermined position in front of the cutter. In this case, the predetermined position may be changed according to a position of the cutter and operating equipment or operating conditions, and the time required to reach the above-described predetermined position at a casting speed during a typical heterogeneous steel operation may be estimated. The reference time may be obtained by using the casting speed and is changed according to the operating equipment or operating conditions as described above.

[0113] An acquisition time is counted in real time while obtaining the dimensionless relative concentration of each of the surface and the center of the strand, and is compared with the reference time in real time (S500), wherein, if the acquisition time is within the reference time (YES), the obtained dimensionless relative concentration of the center is compared with the first reference concentration and the obtained dimensionless relative concentration of the surface is compared with the second reference concentration (S600).

[0114] In this case, the position in the longitudinal direction of the strand, in which the dimensionless relative concentration of the center reaches the first reference concentration, is set as a starting point, and the position in the longitudinal direction of the strand, in which the dimensionless relative concentration of the surface reaches the second reference concentration, is set as an end point so that a position from the starting point to the end point of the mixed portion is predicted as a position of the mixed portion (S700). That is, when the dimensionless relative concentration of the center reaches the first reference concentration, the acquisition of the dimensionless relative concentration of the center is repeated or terminated, and the position of the strand, in which the dimensionless relative concentration of the center reaches the first reference concentration, is set as a starting position, i.e., the first cut-off position, of the mixed portion. Also, when the dimensionless relative concentration of the surface reaches the second reference concentration, the acquisition of the dimensionless relative concentration of the surface is repeated or terminated, and the position of the strand, in which the dimensionless relative concentration of the surface reaches the second reference concentration, is set as an end position, i.e., the second cut-off position, of the mixed portion. Thereafter, the cutter cuts off the predicted mixed portion from the strand by cutting the strand at the first cut-off position and the second cut-off position (S1100).

[0115] In contrast, when the dimensionless relative concentration of the center does not reach the first reference concentration or the dimensionless relative concentration of the surface does not reach the second reference concentration, the obtaining of the dimensionless relative concentrations of each of the surface and the center of the strand (S410) and the calculating of the positions of the corresponding dimensionless relative concentrations (S420) are repeated. Also, for example, in a case in which the dimensionless relative concentration of the center reaches the first reference concentration, but the dimensionless relative concentration of the surface does not reach the second reference concentration, the acquisition of the dimensionless relative concentration of the center is repeated or terminated and the process of the obtaining of the dimensionless relative concentration of the surface and the calculation of the position is again performed. In contrast, in a case in which the dimensionless relative concentration of the surface reaches the second reference concentration, but the dimensionless relative concentration of the center does not reach the first reference concentration, the acquisition of the dimensionless relative concentration of the surface is repeated or terminated and the process of the obtaining of the dimensionless relative concentration of the center and the calculation of the position is again performed.

[0116] As another case example, an acquisition time is counted in real time while obtaining the dimensionless relative concentration of each of the surface and the center of the strand, and is compared with the reference time in real time (S500), wherein, if the acquisition time exceeds the reference time (NO), the acquisition of the dimensionless relative concentration of each of the surface and the center of the strand is terminated (S800). In addition, it is determined whether or not a combination of the previous steel and the subsequent steel subjected to a current operation is a type that is included in the preset mixed portion cut-off length table (S900).

[0117] For example, in a case in which the combination of the heterogeneous steels subjected to the current operation is a type that is included in the preset mixed portion cut-off length table, the strand is cut to the cut-off length listed in the mixed portion cut-off length table (S1200). In this case, the strand may be cut to a corresponding cut-off length based on the position of the meniscus of the strand. However, in a case in which the combination of the heterogeneous steels subjected to the current operation is a type that is not included in the preset mixed portion cut-off length table, the strand is cut to a maximum cut-off length based on the position of the meniscus of the strand (S1300).

[0118] Referring to FIGS. 13 and 14, it may be understood that the position or the cut-off position of the mixed portion calculated by the method of the exemplary embodiment and the position or the cut-off position of the mixed portion detected by direct measurement of the components of the strand coincide with each other. Also, as illustrated in FIG. 14, when the dimensionless relative concentration of the center reaches the first reference concentration and the dimensionless relative concentration of the surface reaches the second reference concentration, the acquisition of the dimensionless relative concentrations of the surface and the calculation of the position is automatically terminated. In the above description, the method of predicting the mixed portion by obtaining the dimensionless concentrations of the surface and the center in the height direction of the strand has been described. However, the positions of the acquisition of the dimensionless concentrations are not limited to the center and the surface, and the mixed portion may be predicted by obtaining dimensionless concentrations at a plurality of positions in the height direction of the strand or positions having different heights of the strand.

[0119] Hereinafter, the method of continuous casting heterogeneous steels according to the exemplary embodiment will be sequentially described with reference to FIGS. 1 to 7 and 12. In this case, steel being first subjected to a casting operation is named as previous steel and steel, in which a casting operation is subsequently started, is named as subsequent steel. Descriptions overlapping with the above-described descriptions will be omitted or will be briefly described.

[0120] First, the casting speed is decreased at an end of operation of the previous steel, and when the residual amount of the previous steel in the tundish is a predetermined amount or less, the programmable logic system (PLC) sends a virtual subsequent ladle opening signal (S200). Thereafter, a weight of the tundish is measured in real time, in milliseconds (ms), for example, 200 ms, from a time when the virtual subsequent ladle opening signal is sent (S220). Subsequently, the weight of the tundish detected in milliseconds (ms) is calculated as an average weight of the tundish in seconds (s), for example, at predetermined time intervals of 1 second or 2 second (S230), and the calculated average weight of the tundish is analyzed in real time to determine whether the average weight of the tundish is continuously increased or not (S240). That is, t-2*Δ t is determined as a time of opening the subsequent ladle when both of $W_{td}(t) - W_{td}(t-\Delta t)$ and $W_{td}(t) - W_{td}(t-2*\Delta t)$ are greater than or equal to "0", and thus, a subsequent ladle opening signal is detected (S200).

[0121] After the sending of the virtual subsequent ladle opening signal (S210), data for the prediction of a mixed portion of the strand are stored in a controller of the continuous casting equipment (S100). That is, a residual amount of the molten steel in the tundish, casting speed, concentrations of components of the molten steel subjected to the current operation (hereinafter, referred to as "previous steel"), and concentrations of components of the molten steel subsequently supplied to the tundish (hereinafter, referred to as "subsequent steel") are received and stored. In this case, the residual-steel amount in the tundish and the casting speed are stored from t-4*Δ t so as to enable the prediction of the mixed portion in real time. Also, with respect to continuous casting equipment in which several strands are generated, it is determined whether or not the equipment is operated for each strand, and casting speed of each strand is stored.

[0122] Next, a first reference concentration and a second reference concentration for predicting the heterogeneous steel mixed portion of the strand solidified and drawn from a mold are set by using the stored concentration data of each component of the previous steel and each component of the subsequent steel (S300). Specifically, a lowermost limit dimensionless concentration value among upper limit dimensionless concentration values of each component of the previous steel is set as the first reference concentration. Also, an uppermost limit dimensionless concentration value among lower limit dimensionless concentration values of each component of the subsequent steel is set as the second reference concentration. During the calculation of the dimensionless concentrations for each component concentration, in a case in which the lower limit dimensionless concentration of the previous steel is greater than the upper limit dimensionless concentration of the previous steel, the lower limit dimensionless concentration value of the previous steel is substituted with the upper limit dimensionless concentration value of the previous steel and the upper limit dimensionless concentration value of the previous steel is substituted with the lower limit dimensionless concentration value of the previous steel. Furthermore, in a case in which the lower limit dimensionless concentration of the subsequent steel is greater than the upper limit dimensionless concentration of the subsequent steel, the lower limit dimensionless concentration value of the subsequent steel is substituted with the upper limit dimensionless concentration value of the subsequent steel and the upper limit dimensionless concentration value of the subsequent steel is substituted with the lower limit dimensionless concentration value of the subsequent steel in the same manner. This is applied when the component concentration of the previous steel is higher than the component concentration of the subsequent steel.

[0123] The first reference concentration and the second reference concentration are reference values for the prediction of the mixed portion, wherein the first reference concentration and the second reference concentration are changed according to the type and combination of the previous steel and the subsequent steel.

[0124] When the first reference concentration and the second reference concentration for the prediction of the mixed portion are set, the dimensionless relative concentration of each of the surface and center of the strand is calculated in real time from the time of detecting the subsequent ladle opening signal, i.e., $t-2^*\Delta t$, and a time for the calculation of the dimensionless relative concentration is counted from the time of detecting the subsequent ladle opening signal ($t-2^*\Delta t$) (S410). Also, a position of the strand at a time of sending the subsequent ladle opening signal is set as a position in which the dimensionless relative concentration of the surface of the strand begins to be measured. In addition, a position of -4 ± 4 m from the position of the strand at the time of opening the subsequent ladle is set as a position in which the dimensionless relative concentration of the center of the strand begins to be obtained.

[0125] As described above, the method of obtaining the dimensionless relative concentrations of the surface and the center includes the processes of: first calculating an inlet volumetric flow (Q_{td-in}) of the subsequent steel in the tundish using Equation 5 (S411), calculating an average dimensionless relative concentration ($C_{td-ave}(t+\Delta t)$) of the molten steel in the tundish at a current time by applying the calculated inlet volumetric flow (Q_{td-in}) of the subsequent steel in the tundish to Equation 6 (S412), calculating a dimensionless relative concentration ($C_{td-out}(t+\Delta t)$) of the molten steel discharged from the tundish at a current time by applying the calculated average dimensionless relative concentration ($C_{td-ave}(t+\Delta t)$) at a current time to Equation 7 (S413), calculating an average dimensionless relative concentration ($C_{md-aver}(t+\Delta t)$) of the molten steel in the mold at a current time by applying the calculated dimensionless relative concentration ($C_{td-out}(t+\Delta t)$) of the molten steel discharged from the tundish at a current time to Equation 8 (S414), and calculating a dimensionless relative concentration ($C_{md-out}(t+\Delta t)$) of the strand discharged from the mold at a current time by applying the calculated dimensionless relative concentration (($C_{td-out}(t+\Delta t)$) of the molten steel discharged from the tundish at a current time and the calculated average dimensionless relative concentration ($C_{md-aver}(t+\Delta t)$) of the molten steel in the mold at a current time to Equation 9 (S415). In this case, since a dimensionless relative concentration ($C_{md-in}(t+\Delta t)$) of the molten steel introduced into the mold at a current time in Equation 9 is the dimensionless relative concentration (($C_{td-out}(t+\Delta t)$) of the molten steel discharged from the tundish at a current time, the dimensionless relative concentration (($C_{td-out}(t+\Delta t)$) of the molten steel discharged from the tundish at a current time calculated by Equation 7 is applied to the dimensionless relative concentration ($C_{md-in}(t+\Delta t)$) of the molten steel introduced into the mold in Equation 9.

[0126] In the above-described method of calculating the concentration, the dimensionless relative concentration of the surface of the strand may be calculated by applying a value of interpolation and extrapolation factor for the calculation of the surface to an interpolation and extrapolation factor (f) of each of Equation 7 for calculating the dimensionless relative concentration (($C_{td-out}(t+\Delta t)$) of the molten steel discharged from the tundish at a current time and Equation 9 for calculating the dimensionless relative concentration ($C_{md-out}(t+\Delta t)$) of the steel discharged from the mold at a current time. That is, the dimensionless relative concentration of the surface of the strand may be obtained when 2.2 ± 0.6 is applied to the interpolation and extrapolation factor (f) of Equation 7 for calculating the dimensionless relative concentration (($C_{td-out}(t+\Delta t)$) of the molten steel discharged from the tundish and 0.5 ± 0.2 is applied to the interpolation and extrapolation factor (f) of Equation 9 for calculating the dimensionless relative concentration ($C_{md-out}(t+\Delta t)$) of the steel discharged from the mold. Similarly, the dimensionless relative concentration of the center of the strand may be obtained when 4 ± 2 is applied to the interpolation and extrapolation factor (f) of Equation 7 for calculating the dimensionless relative concentration (($C_{td-out}(t+\Delta t)$) of the molten steel discharged from the tundish at a current time and 0.7 ± 0.4 is applied to the interpolation and extrapolation factor (f) of Equation 9 for calculating the dimensionless relative concentration ($C_{md-out}(t+\Delta t)$) of the steel discharged from the mold at a current time.

[0127] When the dimensionless relative concentrations of each of the surface and the center of the strand are obtained in real time, positions in the longitudinal direction of the strand having the calculated dimensionless relative concentration of the center and the calculated dimensionless relative concentration of the surface are calculated (S420). The position of the strand having the calculated dimensionless relative concentration of the surface may be calculated by dividing a product of a mold discharge volumetric flow ($Q_{md\text{-}out}$) in the strand and liquid density of the molten metal by a product of a cross-sectional area (A_{md}) of the strand and solid density (ρ_s) of the molten steel as illustrated in Equation 10. Herein, a solid density of the molten steel of 7,600 kg/m^3 to 8,000 kg/m^3, for example, approximately 7,800 kg/m^3 is used as a density value. In addition, the position of the strand having the obtained dimensionless relative concentration of the center is a position of -4$\pm$4 m from the position of the strand having the dimensionless relative concentration of the surface calculated at the same time.

[0128] The dimensionless relative concentrations of each of the surface and the center of the strand are obtained by the above-described method, and a time of calculating the concentration is compared with the reference time in real time while the positions in the longitudinal direction of the strand having the obtained dimensionless relative concentrations of each of the surface and the center are calculated (S500). If the calculation time is within the reference time (YES), the calculated dimensionless relative concentrations of each of the center and the surface of the strand are respectively compared with the first reference concentration and the second reference concentration (S600).

[0129] When the dimensionless relative concentration of the center obtained in real time reaches the first reference concentration and the dimensionless relative concentration of the surface reaches the second reference concentration, the calculation of the concentration is terminated and the mixed portion is predicted and set (S700). That is, when the dimensionless relative concentration of the center obtained in real time reaches the first reference concentration, the calculation of the position in the longitudinal direction of the strand having the dimensionless relative concentration of the center is terminated, and the position of the strand, in which the dimensionless relative concentration of the center reaches the first reference concentration, is set as a starting position. Also, when the dimensionless relative concentration of the surface obtained in real time reaches the second reference concentration, the calculation of the position in the longitudinal direction of the strand having the dimensionless relative concentration of the surface is terminated, and the position of the strand, in which the dimensionless relative concentration of the surface reaches the second reference concentration, is set as an end position. Herein, a region from the position of the strand in which the obtained dimensionless relative concentration of the center has a first reference concentration value to the position of the strand in which the obtained dimensionless relative concentration of the surface has a second reference concentration value is predicted as the mixed portion. Thereafter, since the cutter automatically cuts the strand at the starting position and the end position, the heterogeneous steel mixed portion is cut off from the strand (S1100).

[0130] When the dimensionless relative concentration of the center does not reach the first reference concentration or the dimensionless relative concentration of the surface does not reach the second reference concentration, the obtaining of the dimensionless relative concentrations of the surface and the center of the strand (S410) and the calculating of the positions of the corresponding dimensionless relative concentrations (S420) are repeated.

[0131] If a time for obtaining the concentration and calculating the position exceeds the reference time (NO), the acquisition of the concentrations of the surface and the center of the strand and the calculation of the positions are terminated (S800). In addition, it is determined whether or not a combination of the previous steel and the subsequent steel subjected to a current operation is a type that is included in a preset mixed portion cut-off length table (S900). For example, in a case in which the combination of the heterogeneous steels subjected to the current operation is a combination that is included in the preset mixed portion cut-off length table, the strand is cut to the cut-off length listed in the mixed portion cut-off length table (S1200). In this case, the strand may be cut to a corresponding cut-off length based on a position of the meniscus of the strand. However, in a case in which the combination of the heterogeneous steels subjected to the current operation is a type that is not included in the preset mixed portion cut-off length table, the strand is cut to a predetermined cut-off length, e.g., a maximum length, based on the position of the meniscus (S1300). After the strand is cut to a predetermined length, the slab before the mixed portion and the slab after the mixed portion are set as abnormal materials and components are verified with a component analyzer.

[0132] FIG. 15 is a graph in which lengths of mixed portions are analyzed by the method of predicting a mixed portion according to the exemplary embodiment for 1 year.

[0133] Referring to FIG. 15, it may be understood that the length of the mixed portion was varied from 0 m to 23 m according to a real-time operation method and a concentration of the steel. That is, in the present disclosure, since the length and the position of the mixed portion were calculated for each operation of heterogeneous steels without cutting the strand to a predetermined length regardless of operating conditions for each operation of heterogeneous steels as in the related art, the mixed portion was predicted and then cut, and thus, its accuracy was improved. Specifically, the dimensionless relative concentrations of each of the surface and the center of the strand are obtained in real time, and the length and the position of the mixed portion were deduced by using the dimensionless relative concentrations. Thus, in the present disclosure, a decrease in profitability due to excessive cut-off of the mixed portion may be prevented, and the shipment of defect products due to less cut-off of the mixed portion to client companies may be prevented.

INDUSTRIAL APPLICABILITY

[0134] A method of continuous casting heterogeneous steels according to the present disclosure may predict a mixed portion of a strand, which is manufactured by mixing previous steel and subsequent steel, and may automatically cut the mixed portion. Thus, since the accuracy of the prediction of the position and the length of the mixed portion is improved, a decrease in profitability due to excessive cut-off of the mixed portion may be prevented and the shipment of defect products due to less cut-off of the mixed portion to client companies may be prevented. Therefore, there is an effect of improving productivity in which a high-quality slab is manufactured in the continuous casting operation of heterogeneous steels.

Claims

1. A method of continuous casting heterogeneous steels, the method comprising:

obtaining dimensionless relative concentrations of subsequent steel to previous steel respectively at surface and inside of a continuous cast strand in real time;
calculating positions in a longitudinal direction of the strand having the dimensionless relative concentrations of the surface and the inside obtained in real time;
predicting a mixed portion in the strand by respectively comparing the obtained dimensionless relative concentrations of the surface and the inside with reference concentrations; and
cutting off the predicted mixed portion.

2. The method of claim 1, wherein the positions of the strand, from which the dimensionless relative concentrations are obtained, are a surface and a center in a height direction of the strand.

3. A method of continuous casting heterogeneous steels, the method comprising:

obtaining dimensionless relative concentrations of subsequent steel to previous steel respectively at a plurality of positions in a height direction of a strand solidified and continuous cast from a mold in real time by using relative amounts of the previous steel and the subsequent steel in a tundish and relative amounts of the previous steel and the subsequent steel in the mold;
calculating positions in a longitudinal direction of the strand having the dimensionless relative concentrations obtained in real time;
predicting a mixed portion in the strand by respectively comparing the obtained dimensionless relative concentrations with reference concentrations; and
cutting off the predicted mixed portion.

4. The method of claim 3, wherein the plurality of positions in the height direction of the strand, from which the dimensionless relative concentrations are obtained, comprises a surface and a center of the strand.

5. The method of claim 1 or 3, further comprising setting the reference concentrations, before the obtaining of the dimensionless relative concentrations of the subsequent steel to the previous steel in the continuous cast strand in real time,
wherein the setting of the reference concentrations comprises:

setting a lowermost limit concentration among upper limit concentrations of each component of the previous steel as a first reference concentration; and
setting an uppermost limit concentration among lower limit concentrations of each component of the subsequent steel as a second reference concentration.

6. The method of claim 5, wherein the setting of the first reference concentration and the second reference concentration comprises:

calculating concentrations of the components of the previous steel as lower limit dimensionless concentrations and upper limit dimensionless concentrations;
setting a lowermost limit dimensionless concentration among the upper limit dimensionless concentrations of the each component of the previous steel as the first reference concentration;

calculating concentrations of the components of the subsequent steel as lower limit dimensionless concentrations and upper limit dimensionless concentrations; and
setting an uppermost limit dimensionless concentration among the lower limit dimensionless concentrations of the each component of the subsequent steel as the second reference concentration.

7. The method of claim 6, wherein the calculating of the concentrations of the each component of the previous steel as the lower limit dimensionless concentrations and the upper limit dimensionless concentrations comprises substituting a lower limit dimensionless concentration value of the previous steel with an upper limit dimensionless concentration value of the previous steel and substituting the upper limit dimensionless concentration value of the previous steel with the lower limit dimensionless concentration value of the previous steel when the lower limit dimensionless concentration of the previous steel is greater than the upper limit dimensionless concentration of the previous steel; and
the calculating of the concentrations of the each component of the subsequent steel as the lower limit dimensionless concentrations and the upper limit dimensionless concentrations comprises substituting a lower limit dimensionless concentration value of the subsequent steel with an upper limit dimensionless concentration value of the subsequent steel and substituting the upper limit dimensionless concentration value of the subsequent steel with the lower limit dimensionless concentration value of the subsequent steel when the lower limit dimensionless concentration of the subsequent steel is greater than the upper limit dimensionless concentration of the subsequent steel.

8. The method of claim 2 or 4, wherein the strand is determined to be in a mixed state when at least one dimensionless relative concentration of the obtained dimensionless relative concentrations of the surface and the center is deviated from the reference concentration, and
a position in the longitudinal direction of the strand, in which at least one dimensionless relative concentration of the obtained dimensionless relative concentrations of the surface and the center is deviated from the reference concentration, is determined as the mixed portion.

9. The method of claim 8, wherein a position in the longitudinal direction of the strand, in which the obtained dimensionless relative concentration of the center reaches the reference concentration, is determined as a starting point of the mixed portion, and
a position in the longitudinal direction of the strand, in which the obtained dimensionless relative concentration of the surface reaches the reference concentration, is determined as an end point of the mixed portion.

10. The method of claim 2 or 4, further comprising:

receiving data of a residual amount of molten steel in the tundish, casting speed, and concentrations of each of the previous steel and the subsequent steel on-line and storing the data; and
detecting a subsequent ladle opening signal, before the obtaining of the dimensionless relative concentrations of the subsequent steel to the previous steel.

11. The method of claim 10, further comprising:

obtaining dimensionless relative concentrations of each of the surface and the center of the strand in real time from a time of detecting the subsequent ladle opening signal, and counting a dimensionless concentration acquisition time from the time of detecting the subsequent ladle opening signal to be compared with a reference time in real time;
comparing the obtained dimensionless relative concentration of the center with the first reference concentration and comparing the obtained dimensionless relative concentration of the surface with the second reference concentration when the dimensionless concentration acquisition time is the reference time or less; and
terminating the acquisition of the dimensionless relative concentrations of each of the surface and the center of the strand when the concentration acquisition time is greater than the reference time.

12. The method of claim 11, further comprising:

determining whether or not a type between the previous steel and the subsequent steel is a type that is included in a preset heterogeneous steel cut-off table;
cutting the strand to a cut-off length of the corresponding heterogeneous steel type when the type between the previous steel and the subsequent steel subjected to a current operation is the type that is included in the preset heterogeneous steel cut-off table; and

cutting the strand to a preset predetermined cut-off length when the type between the previous steel and the subsequent steel subjected to the current operation is not included in the preset heterogeneous steel cut-off table, after the terminating of the acquisition of the dimensionless relative concentrations of each of the surface and the center of the strand.

13. The method of claim 10, wherein the detecting of the subsequent ladle opening signal comprises:

sending a virtual ladle opening signal;
detecting a weight of the tundish in real time, in milliseconds (ms) from a time when the virtual ladle opening signal is sent;
calculating the weight of the tundish detected in milliseconds (ms) as an average weight of the tundish at predetermined time intervals in seconds (s); and
setting a time of opening the subsequent ladle using a time of continuously increasing the average weight of the tundish.

14. The method of claim 13, wherein, when $W_{td}(t)$ is a weight of a residual-steel amount in the tundish at a current time and $W_{dt}(t-\Delta t)$ is a weight of a residual-steel amount in the tundish at an earlier time,
$t-2^*\Delta t$ is determined as the time of opening the subsequent ladle when both of $W_{td}(t) - W_{td}(t-\Delta t)$ and $W_{td}(t) - W_{td}(t-2^*\Delta t)$ are greater than or equal to "0",
the dimensionless relative concentrations of each of the surface and the center of the strand are obtained from $t-2^*\Delta t$, and
the residual-steel amount in the tundish and the casting speed are stored from $t-4^*\Delta t$.

15. The method of claim 2 or 4, wherein the obtaining of the dimensionless relative concentrations of the subsequent steel to the previous steel at the surface and the center of the strand comprises:

calculating an inlet volumetric flow (Q_{td-in}) of the subsequent steel in the tundish;
calculating an average dimensionless relative concentration ($C_{td-ave}(t+\Delta t)$) of the molten steel in the tundish at a current time using the inlet volumetric flow (Q_{td-in}) of the subsequent steel in the tundish;
calculating a dimensionless relative concentration ($C_{td-out}(t+\Delta t)$) of the molten steel discharged from the tundish at a current time using the average dimensionless relative concentration ($C_{td-ave}(t+\Delta t)$) of the molten steel in the tundish at a current time;
calculating an average dimensionless relative concentration ($C_{md-aver}(t+\Delta t)$) of the molten steel in the mold at a current time using the dimensionless relative concentration ($C_{td-out}(t+\Delta t)$) of the molten steel discharged from the tundish at a current time; and
calculating a dimensionless relative concentration ($C_{md-out}(t+\Delta t)$) of the strand discharged from the mold at a current time using the average dimensionless relative concentration ($C_{md-aver}(t+\Delta t)$) of the molten steel in the mold at a current time and a dimensionless relative concentration ($C_{md-in}(t+\Delta t)$) of the molten steel introduced into the mold at a current time.

16. The method of claim 15, wherein the inlet volumetric flow (Q_{td-in}) of the subsequent steel in the tundish is calculated by Equation 5,

[Equation 5]

$$Q_{td-in} = \frac{W_{td}(t+\Delta t) - W_{td}(t)}{\Delta t \times \rho_L} + Q_{td-out}$$

wherein $W_{td}(t)$ is a total weight of the molten steel in the tundish at an earlier time, $W_{td}(t+\Delta t)$ is a total weight of the molten steel in the tundish at a current time, Q_{td-out} is a volumetric flow of the molten steel discharged from the tundish, and ρ_L is liquid density of the molten steel, the average concentration ($C_{td\text{-}ave}(t+\Delta t)$) of the molten steel in the tundish at a current time is calculated by Equation 6,

[Equation 6]

$$C_{td\text{-}ave}(t+\Delta t)=\frac{W_{td}(t)\times C_{td\text{-}ave}(t)+Q_{td\text{-}in}(t)\times\Delta t\times\rho_L\times C_{td\text{-}in}(t)}{W_{td}(t+\Delta t)}-\frac{Q_{td\text{-}out}(t)\times\Delta t\times\rho_L\times C_{td\text{-}out}(t)}{W_{td}(t+\Delta t)}$$

wherein $C_{td\text{-}ave}(t)$ is an average dimensionless relative concentration of the molten steel in the tundish at an earlier time, $Q_{td\text{-}in}(t)$ is an inlet volumetric flow of the molten steel introduced into the tundish at an earlier time, $C_{td\text{-}in}(t)$ is an inlet concentration (dimensionless relative concentration) of the subsequent steel in the tundish at an earlier time, $Q_{td\text{-}out}(t)$ is a volumetric flow of the molten steel discharged from the tundish at an earlier time, $C_{td\text{-}out}(t)$ is a concentration (dimensionless relative concentration) of the molten steel discharged from the tundish at an earlier time, and ρ_L is liquid density of the molten steel,
the concentration (($C_{td\text{-}out}(t+\Delta t)$) of the molten steel discharged from the tundish at a current time is calculated by Equation 7,

[Equation 7]

$$C_{td\text{-}out}(t+\Delta t)=f_{td}\times C_{td\text{-}ave}(t+\Delta t)+(1-f_{td})\times C_{td\text{-}in}(t+\Delta t)$$

wherein f_{td} is an interpolation and extrapolation factor of the tundish, $C_{td\text{-}ave}(t+\Delta t)$ is an average dimensionless relative concentration of the molten steel in the tundish at a current time, and $C_{td\text{-}in}(t+\Delta t)$ is a dimensionless relative concentration of the molten steel introduced into the tundish at a current time,
the average concentration ($C_{md\text{-}aver}(t+\Delta t)$) of the molten steel in the mold at a current time is calculated by Equation 8,

[Equation 8]

$$C_{md\text{-}ave}(t+\Delta t)=\frac{W_{md}(t)\times C_{md\text{-}ave}(t)+Q_{md\text{-}in}(t)\times\Delta t\times\rho_L\times C_{md\text{-}in}(t)}{W_{md}(t+\Delta t)}-\frac{Q_{md\text{-}out}(t)\times\Delta t\times\rho_L\times C_{md\text{-}out}(t)}{W_{md}(t+\Delta t)}$$

wherein $W_{md}(t)$ is a total weight of the molten steel in the mold at an earlier time, $C_{md\text{-}aver}(t)$ is an average dimensionless relative concentration of the molten steel in the mold at an earlier time, $Q_{md\text{-}in}(t)$ is an inlet volumetric flow of the molten steel in the mold at an earlier time, $C_{md\text{-}in}(t)$ is an inlet concentration (dimensionless relative concentration) of the molten steel in the mold at an earlier time, $W_{md}(t+\Delta t)$ is a total weight of the molten steel in the mold at a current time, $Q_{md\text{-}out}(t)$ is a volumetric flow of the molten steel discharged from the mold, $C_{md\text{-}out}(t)$ is a dimensionless relative concentration of the strand discharged from the mold at an earlier time, and ρ_L is liquid density of the molten steel, and
the concentration ($C_{md\text{-}out}(t+\Delta t)$) of the strand discharged from the mold at a current time is calculated by Equation 9,

[Equation 9]

$$C_{md\text{-}out}(t+\Delta t)=f_{md}\times C_{md\text{-}ave}(t+\Delta t)+(1-f_{md})\times C_{md\text{-}in}(t+\Delta t)$$

wherein f_{md} is an interpolation and extrapolation factor of the mold, $C_{md\text{-}aver}(t+\Delta t)$ is an average dimensionless relative concentration of the molten steel in the mold at a current time, and $C_{md\text{-}in}(t+\Delta t)$ is a dimensionless relative concentration of the molten steel introduced into the mold at a current time.

17. The method of claim 16, wherein, in the calculating of the dimensionless relative concentration of the center of the strand,
4±2 is applied to the interpolation and extrapolation factor (f_{td}) of Equation 7, and

0.7±0.4 is applied to the interpolation and extrapolation factor (f_{md}) of Equation 9 to calculate the dimensionless relative concentration ($C_{md\text{-}out\text{-}center}$) of the center of the strand.

18. The method of claim 16, wherein in the calculating of the dimensionless relative concentration of the surface of the strand,
2.2±0.6 is applied to the interpolation and extrapolation factor (f_{td}) of Equation 7, and
0.5±0.2 is applied to the interpolation and extrapolation factor (f_{md}) of Equation 9 to calculate the dimensionless relative concentration ($C_{md\text{-}out\text{-}surface}$) of the surface of the strand.

19. The method of claim 16, wherein a liquid density of the molten steel is used as a density (ρ_L) value in Equations 5, 6, and 8, and
a value of 7,000 kg/m^3 to 7,400 kg/m^3 is used as the density of the molten steel.

20. The method of claim 10, further comprising:

setting a position of the strand in which the dimensionless relative concentration of the surface of the strand begins to be obtained; and
setting a position of the strand in which the dimensionless relative concentration of the center of the strand begins to be obtained,
wherein a position of the strand at the time of opening the subsequent ladle is set as the position in which the dimensionless relative concentration of the surface of the strand begins to be obtained, and
a position of -4±4 m from the position of the strand at the time of opening the subsequent ladle is set as the position in which the dimensionless relative concentration of the center of the strand begins to be obtained.

21. The method of claim 20, wherein, in the calculating of the position in the longitudinal direction of the strand having the obtained dimensionless relative concentration of the surface,
the position is calculated by Equation 10 in which a volumetric flow ($Q_{md\text{-}out}$) of the molten steel discharged from the mold is divided by a product of a cross-sectional area (A_{md}) of the strand and solid density (ρ_s) of the molten steel,

[Equation 10]

$$L(t+\Delta t)=L(t)+\frac{Q_{md\text{-}out} \times \rho_l}{A_{md} \times \rho_S} \times \Delta t$$

wherein $Q_{md\text{-}out}$ is a volumetric flow of the molten steel discharged from the mold, A_{md} is a cross-sectional area of the strand, and ρ_s is solid density of the molten steel, wherein a value of 7,600 kg/m^3 to 8,000 kg/m^3 is used.

22. The method of claim 21, wherein, in the calculating of the position in the longitudinal direction of the strand having the obtained dimensionless relative concentration of the center,
a position of -4±4 m from the position having the obtained dimensionless relative concentration of the surface is set as the position having the dimensionless relative concentration of the center.

23. The method of claim 22, wherein a region from a point of the strand, in which the real-time obtained dimensionless relative concentration of the center of the strand reaches the first reference concentration, to a point of the strand, in which the real-time obtained dimensionless relative concentration of the surface of the strand reaches the second reference concentration, is predicted as the mixed portion.

24. The method of claim 22, further comprising:

setting the point of the strand, in which the real-time obtained dimensionless relative concentration of the center of the strand reaches the first reference concentration, as a first cut-off position;
setting the point of the strand, in which the real-time obtained dimensionless relative concentration of the surface of the strand reaches the second reference concentration, as a second cut-off position; and

cutting off the mixed portion by cutting the strand respectively at the first cut-off position and the second cut-off position.

25. The method of claim 1 or 3, wherein the predicting of the mixed portion of the strand and the cutting off of the predicted mixed portion are performed as an online process.

Patentansprüche

1. Verfahren zum Stranggießen von heterogenen Stählen, wobei das Verfahren umfasst:

   Erhalten dimensionsloser Relativkonzentrationen von nachfolgendem Stahl zu vorausgehendem Stahl jeweils an der Oberfläche und im Innern eines stranggegossenen Strangs in Echtzeit;
   Berechnen von Positionen in einer Längsrichtung des Strangs, welche die in Echtzeit erhaltenen dimensionslosen Relativkonzentrationen der Oberfläche und des Innern aufweisen;
   Vorhersagen eines gemischten Abschnitts in dem Strang durch jeweiliges Vergleichen der erhaltenen dimensionslosen Relativkonzentrationen der Oberfläche und des Innern mit Referenzkonzentrationen; und
   Abschneiden des vorhergesagten gemischten Abschnitts.

2. Verfahren nach Anspruch 1, wobei die Positionen des Strangs, von denen die dimensionslosen Relativkonzentrationen erhalten werden, eine Oberfläche und eine Mitte in einer Höhenrichtung des Strangs sind.

3. Verfahren zum Stranggießen von heterogenen Stählen, wobei das Verfahren umfasst:

   Erhalten dimensionsloser Relativkonzentrationen von nachfolgendem Stahl zu vorausgehendem Stahl jeweils an einer Vielzahl von Positionen in einer Höhenrichtung eines erstarrten und aus einer Kokille stranggegossenen Strangs in Echtzeit unter Verwendung relativer Mengen des vorausgehenden Stahls und des nachfolgenden Stahls in einem Zwischenbehälter und relativer Mengen des vorausgehenden Stahls und des nachfolgenden Stahls in der Kokille;
   Berechnen von Positionen in einer Längsrichtung des Strangs, welche die in Echtzeit erhaltenen dimensionslosen Relativkonzentrationen aufweisen;
   Vorhersagen eines gemischten Abschnitts in dem Strang durch jeweiliges Vergleichen der erhaltenen dimensionslosen Relativkonzentrationen mit Referenzkonzentrationen; und
   Abschneiden des vorhergesagten gemischten Abschnitts.

4. Verfahren nach Anspruch 3, wobei die Vielzahl von Positionen in der Höhenrichtung des Strangs, von der die dimensionslosen Relativkonzentrationen erhalten werden, eine Oberfläche und eine Mitte des Strangs umfasst.

5. Verfahren nach Anspruch 1 oder 3, weiterhin umfassend das Festlegen der Referenzkonzentrationen vor dem Erhalten der dimensionslosen Relativkonzentrationen des nachfolgenden Stahls zum vorausgehenden Stahl in dem stranggegossenen Strang in Echtzeit,
   wobei das Festlegen der Referenzkonzentrationen umfasst:

   Festlegen einer untersten Grenzkonzentration unter oberen Grenzkonzentrationen jeder Komponente des vorausgehenden Stahls als eine erste Referenzkonzentration; und
   Festlegen einer obersten Grenzkonzentration unter unteren Grenzkonzentrationen jeder Komponente des nachfolgenden Stahls als eine zweite Referenzkonzentration.

6. Verfahren nach Anspruch 5, wobei das Festlegen der ersten Referenzkonzentration und der zweiten Referenzkonzentration umfasst:

   Berechnen von Konzentrationen der Komponenten des vorausgehenden Stahls als dimensionslose untere Grenzkonzentrationen und dimensionslose obere Grenzkonzentrationen;
   Festlegen einer dimensionslosen untersten Grenzkonzentration unter den dimensionslosen oberen Grenzkonzentrationen der jeweiligen Komponente des vorausgehenden Stahls als erste Referenzkonzentration;
   Berechnen von Konzentrationen der Komponenten des nachfolgenden Stahls als dimensionslose untere Grenzkonzentrationen und dimensionslose obere Grenzkonzentrationen; und
   Festlegen einer dimensionslosen obersten Grenzkonzentration unter den dimensionslosen unteren Grenzkon-

zentrationen der jeweiligen Komponente des nachfolgenden Stahls als zweite Referenzkonzentration.

7. Verfahren nach Anspruch 6, wobei das Berechnen der Konzentrationen der jeweiligen Komponente des vorausgehenden Stahls als dimensionslose untere Grenzkonzentrationen und dimensionslose obere Grenzkonzentrationen das Ersetzen eines dimensionslosen unteren Grenzkonzentrationswerts des vorausgehenden Stahls durch einen dimensionslosen oberen Grenzkonzentrationswert des vorausgehenden Stahls und das Ersetzen des dimensionslosen oberen Grenzkonzentrationswerts des vorausgehenden Stahls durch den dimensionslosen unteren Grenzkonzentrationswert des vorausgehenden Stahls umfasst, wenn die dimensionslose untere Grenzkonzentration des vorausgehenden Stahls größer ist als die dimensionslose obere Grenzkonzentration des vorausgehenden Stahls; und
das Berechnen der Konzentrationen der jeweiligen Komponente des nachfolgenden Stahls als dimensionslose untere Grenzkonzentrationen und dimensionslose obere Grenzkonzentrationen das Ersetzen eines dimensionslosen unteren Grenzkonzentrationswerts des nachfolgenden Stahls durch einen dimensionslosen oberen Grenzkonzentrationswert des nachfolgenden Stahls und das Ersetzen des dimensionslosen oberen Grenzkonzentrationswerts des nachfolgenden Stahls durch den dimensionslosen unteren Grenzkonzentrationswert des nachfolgenden Stahls umfasst, wenn die dimensionslose untere Grenzkonzentration des nachfolgenden Stahls größer ist als die dimensionslose obere Grenzkonzentration des nachfolgenden Stahls.

8. Verfahren nach Anspruch 2 oder 4, wobei der Strang als in einem Mischzustand befindlich bestimmt wird, wenn wenigstens eine dimensionslose Relativkonzentration der erhaltenen dimensionslosen Relativkonzentrationen der Oberfläche und der Mitte von der Referenzkonzentration abgewichen ist, und
eine Position in der Längsrichtung des Strangs, an der wenigstens eine dimensionslose Relativkonzentration der erhaltenen dimensionslosen Relativkonzentrationen der Oberfläche und der Mitte von der Referenzkonzentration abgewichen ist, als der gemischte Abschnitt bestimmt wird.

9. Verfahren nach Anspruch 8, wobei eine Position in der Längsrichtung des Strangs, an der die erhaltene dimensionslose Relativkonzentration der Mitte die Referenzkonzentration erreicht, als Anfangspunkt des gemischten Abschnitts bestimmt wird, und
eine Position in der Längsrichtung des Strangs, an der die erhaltene dimensionslose Relativkonzentration der Oberfläche die Referenzkonzentration erreicht, als Endpunkt des gemischten Abschnitts bestimmt wird.

10. Verfahren nach Anspruch 2 oder 4, weiterhin umfassend:

Online-Empfang von Daten über eine Restmenge an geschmolzenem Stahl in dem Zwischenbehälter, Gießgeschwindigkeit und Konzentrationen des jeweiligen vorausgehenden Stahls und des jeweiligen nachfolgenden Stahls und Speichern der Daten; und
Erkennung eines Signals der Öffnung der nachfolgenden Gießpfanne vor dem Erhalten der dimensionslosen Relativkonzentrationen des nachfolgenden Stahls zum vorausgehenden Stahl.

11. Verfahren nach Anspruch 10, weiterhin umfassend:

Erhalten von dimensionslosen Relativkonzentrationen der jeweiligen Oberfläche und der jeweiligen Mitte des Strangs in Echtzeit ab einem Zeitpunkt der Erkennung des Öffnungssignals der nachfolgenden Gießpfanne, und Zählen einer Erfassungszeit der dimensionslosen Konzentration ab dem Zeitpunkt der Erkennung des Öffnungssignals der nachfolgenden Gießpfanne, die mit einer Referenzzeit in Echtzeit verglichen werden soll;
Vergleichen der erhaltenen dimensionslosen Relativkonzentration der Mitte mit der ersten Referenzkonzentration und Vergleichen der erhaltenen dimensionslosen Relativkonzentration der Oberfläche mit der zweiten Referenzkonzentration, wenn die Erfassungszeit der dimensionslosen Konzentration der Referenzzeit entspricht oder kürzer ist; und
Beenden der Erfassung der dimensionslosen Relativkonzentrationen der jeweiligen Oberfläche und der jeweiligen Mitte des Strangs, wenn die Konzentrationserfassungszeit länger ist als die Referenzzeit.

12. Verfahren nach Anspruch 11, weiterhin umfassend:

Bestimmen, ob ein Typ zwischen dem vorausgehenden Stahl und dem nachfolgenden Stahl ein Typ ist, der in einer vorgegebenen Abschneide-Tabelle für heterogenen Stahl enthalten ist, oder nicht;
Schneiden des Strangs auf eine Abschneidelänge des entsprechenden heterogenen Stahltyps, wenn der Typ zwischen dem vorausgehenden Stahl und dem nachfolgenden Stahl, die einem gegenwärtigen Arbeitsgang

unterzogen werden, der Typ ist, der in der vorgegebenen Abschneide-Tabelle für heterogenen Stahl enthalten ist; und
Schneiden des Strangs auf eine vorgegebene vorbestimmte Abschneidelänge, wenn der Typ zwischen dem vorausgehenden Stahl und dem nachfolgenden Stahl, die dem gegenwärtigen Arbeitsgang unterzogen werden, nicht in der vorgegebenen Abschneide-Tabelle für heterogenen Stahl enthalten ist, nach dem Beenden der Erfassung der dimensionslosen Relativkonzentrationen der jeweiligen Oberfläche und der jeweiligen Mitte des Strangs.

13. Verfahren nach Anspruch 10, wobei die Erkennung des Öffnungssignals der nachfolgenden Gießpfanne umfasst:

Senden eines virtuellen Gießpfannenöffnungssignals;
Erfassen eines Gewichts des Zwischenbehälters in Echtzeit, in Millisekunden (ms) ab einem Zeitpunkt, an dem das virtuelle Gießpfannenöffnungssignal gesendet wird;
Berechnen des in Millisekunden (ms) erfassten Gewichts des Zwischenbehälters als Durchschnittsgewicht des Zwischenbehälters in vorbestimmten Zeitintervallen in Sekunden (s); und
Festlegen eines Zeitpunkts der Öffnung der nachfolgenden Gießpfanne mittels eines Zeitpunkts der kontinuierlichen Erhöhung des Durchschnittsgewichts des Zwischenbehälters.

14. Verfahren nach Anspruch 13, wobei, wenn $W_{td}(t)$ ein Gewicht einer Reststahlmenge in dem Zwischenbehälter zu einem gegenwärtigen Zeitpunkt ist und $W_{dt}(t-\Delta t)$ ein Gewicht einer Reststahlmenge in dem Zwischenbehälter zu einem früheren Zeitpunkt ist,
$t-2*\Delta t$ als der Zeitpunkt der Öffnung der nachfolgenden Gießpfanne bestimmt wird, wenn sowohl $W_{td}(t) - W_{td}(t-\Delta t)$ als auch $W_{td}(t) - W_{td}(t-2*\Delta t)$ größer als oder gleich "0" sind,
die dimensionslosen Relativkonzentrationen der jeweiligen Oberfläche und der jeweiligen Mitte des Strangs ab $t-2*\Delta t$ erhalten werden, und
die Reststahlmenge in dem Zwischenbehälter und die Gießgeschwindigkeit ab $t-4*\Delta t$ gespeichert werden.

15. Verfahren nach Anspruch 2 oder 4, wobei das Erhalten der dimensionslosen Relativkonzentrationen des nachfolgenden Stahls zum vorausgehenden Stahl an der Oberfläche und in der Mitte des Strangs umfasst:

Berechnen eines Eintrittsvolumenstroms (Q_{td-in}) des nachfolgenden Stahls in dem Zwischenbehälter;
Berechnen einer durchschnittlichen dimensionslosen Relativkonzentration ($C_{td-ave}(t+\Delta t)$) des geschmolzenen Stahls in dem Zwischenbehälter zu einem gegenwärtigen Zeitpunkt mittels des Eintrittsvolumenstroms (Q_{td-in}) des nachfolgenden Stahls in dem Zwischenbehälter;
Berechnen einer dimensionslosen Relativkonzentration ($C_{td-out}(t+\Delta t)$) des aus dem Zwischenbehälter austretenden geschmolzenen Stahls zu einem gegenwärtigen Zeitpunkt mittels der durchschnittlichen dimensionslosen Relativkonzentration ($C_{td-ave}(t+\Delta t)$) des geschmolzenen Stahls in dem Zwischenbehälter zu einem gegenwärtigen Zeitpunkt;
Berechnen einer durchschnittlichen dimensionslosen Relativkonzentration ($C_{md-aver}(t+\Delta t)$) des geschmolzenen Stahls in der Kokille zu einem gegenwärtigen Zeitpunkt mittels der dimensionslosen Relativkonzentration ($C_{td-out}(t+\Delta t)$) des aus dem Zwischenbehälter austretenden geschmolzenen Stahls zu einem gegenwärtigen Zeitpunkt; und
Berechnen einer dimensionslosen Relativkonzentration ($C_{md-out}(t+\Delta t)$) des aus der Kokille austretenden Strangs zu einem gegenwärtigen Zeitpunkt mittels der durchschnittlichen dimensionslosen Relativkonzentration ($C_{md-aver}(t+\Delta t)$) des geschmolzenen Stahls in der Kokille zu einem gegenwärtigen Zeitpunkt und einer dimensionslosen Relativkonzentration ($C_{md-in}(t+\Delta t)$) des in die Kokille eingeleiteten geschmolzenen Stahls zu einem gegenwärtigen Zeitpunkt.

16. Verfahren nach Anspruch 15, wobei der Eintrittsvolumenstrom (Q_{td-in}) des nachfolgenden Stahls in dem Zwischenbehälter durch Gleichung 5 berechnet wird,

[Gleichung 5]

$$Q_{td\text{-}in} = \frac{W_{td}(t+\Delta t) - W_{td}(t)}{\Delta t \times \rho_L} + Q_{td\text{-}out}$$

wobei $W_{td}(t)$ ein Gesamtgewicht des geschmolzenen Stahls in dem Zwischenbehälter zu einem früheren Zeitpunkt ist, $W_{td}(t+\Delta t)$ ein Gesamtgewicht des geschmolzenen Stahls in dem Zwischenbehälter zu einem gegenwärtigen Zeitpunkt ist, $Q_{td\text{-}out}$ ein Volumenstrom des aus dem Zwischenbehälter austretenden geschmolzenen Stahls ist und ρ_L die Flüssigdichte des geschmolzenen Stahls ist,
die durchschnittliche Konzentration ($C_{td\text{-}ave}(t+\Delta t)$) des geschmolzenen Stahls in dem Zwischenbehälter zu einem gegenwärtigen Zeitpunkt durch Gleichung 6 berechnet wird,

[Gleichung 6]

$$C_{td\text{-}ave}(t+\Delta t)=\frac{W_{td}(t)\times C_{td\text{-}ave}(t)+Q_{td\text{-}in}(t)\times\Delta t\times\rho_L\times C_{td\text{-}in}(t)}{W_{td}(t+\Delta t)}-\frac{Q_{td\text{-}out}(t)\times\Delta t\times\rho_L\times C_{td\text{-}out}(t)}{W_{td}(t+\Delta t)}$$

wobei $C_{td\text{-}ave}(t)$ eine durchschnittliche dimensionslose Relativkonzentration des geschmolzenen Stahls in dem Zwischenbehälter zu einem früheren Zeitpunkt ist, $Q_{td\text{-}in}(t)$ ein Eintrittsvolumenstrom des in den Zwischenbehälter eingeleiteten geschmolzenen Stahls zu einem früheren Zeitpunkt ist, $C_{td\text{-}in}(t)$ eine Eintrittskonzentration (dimensionslose Relativkonzentration) des nachfolgenden Stahls in dem Zwischenbehälter zu einem früheren Zeitpunkt ist, $Q_{td\text{-}out}(t)$ ein Volumenstrom des aus dem Zwischenbehälter austretenden geschmolzenen Stahls zu einem früheren Zeitpunkt ist, $C_{td\text{-}out}(t)$ eine Konzentration (dimensionslose Relativkonzentration) des aus dem Zwischenbehälter austretenden geschmolzenen Stahls zu einem früheren Zeitpunkt ist und ρ_L die Flüssigdichte des geschmolzenen Stahls ist,
die Konzentration (($C_{td\text{-}out}(t+\Delta t)$) des aus dem Zwischenbehälter austretenden geschmolzenen Stahls zu einem gegenwärtigen Zeitpunkt durch Gleichung 7 berechnet wird,

[Gleichung 7]

$$C_{td\text{-}out}(t+\Delta t)=f_{td}\times C_{td\text{-}ave}(t+\Delta t)+(1-f_{td})\times C_{td\text{-}in}(t+\Delta t)$$

wobei f_{td} ein Interpolations- und Extrapolationsfaktor des Zwischenbehälters ist, $C_{td\text{-}ave}(t+\Delta t)$ eine durchschnittliche dimensionslose Relativkonzentration des geschmolzenen Stahls in dem Zwischenbehälter zu einem gegenwärtigen Zeitpunkt ist und $C_{td\text{-}in}(t+\Delta t)$ eine dimensionslose Relativkonzentration des in den Zwischenbehälter eingeleiteten geschmolzenen Stahls zu einem gegenwärtigen Zeitpunkt ist,
die durchschnittliche Konzentration ($C_{md\text{-}aver}(t+\Delta t)$) des geschmolzenen Stahls in der Kokille zu einem gegenwärtigen Zeitpunkt durch Gleichung 8 berechnet wird,

[Gleichung 8]

$$C_{md\text{-}ave}(t+\Delta t)=\frac{W_{md}(t)\times C_{md\text{-}ave}(t)+Q_{md\text{-}in}(t)\times\Delta t\times\rho_L\times C_{md\text{-}in}(t)}{W_{md}(t+\Delta t)}-\frac{Q_{md\text{-}out}(t)\times\Delta t\times\rho_L\times C_{md\text{-}out}(t)}{W_{md}(t+\Delta t)}$$

wobei $W_{md}(t)$ ein Gesamtgewicht des geschmolzenen Stahls in der Kokille zu einem früheren Zeitpunkt ist, $C_{md\text{-}aver}(t)$ eine durchschnittliche dimensionslose Relativkonzentration des geschmolzenen Stahls in der Kokille zu einem früheren Zeitpunkt ist, $Q_{md\text{-}in}(t)$ ein Eintrittsvolumenstrom des geschmolzenen Stahls in der Kokille zu einem früheren Zeitpunkt ist, $C_{md\text{-}in}(t)$ eine Eintrittskonzentration (dimensionslose Relativkonzentration) des geschmolzenen Stahls in der Kokille zu einem früheren Zeitpunkt ist, $W_{md}(t+\Delta t)$ ein Gesamtgewicht des geschmolzenen Stahls in der Kokille zu einem gegenwärtigen Zeitpunkt ist, $Q_{md\text{-}out}(t)$ ein Volumenstrom des aus der Kokille austretenden geschmolzenen Stahls ist, $C_{md\text{-}out}(t)$ eine dimensionslose Relativkonzentration des aus der Kokille austretenden Strangs zu einem früheren Zeitpunkt ist und ρ_L die Flüssigdichte des geschmolzenen Stahls ist, und
die Konzentration ($C_{md\text{-}out}(t+\Delta t)$) des aus der Kokille austretenden Strangs zu einem gegenwärtigen Zeitpunkt durch Gleichung 9 berechnet wird,

[Gleichung 9]

$$C_{md\text{-}out}(t+\Delta t)=f_{md}\times C_{md\text{-}ave}(t+\Delta t)+(1-f_{md})\times C_{md\text{-}in}(t+\Delta t)$$

wobei f_{md} ein Interpolations- und Extrapolationsfaktor der Kokille ist, $C_{md\text{-}aver}(t+\Delta t)$ eine durchschnittliche dimensionslose Relativkonzentration des geschmolzenen Stahls in der Kokille zu einem gegenwärtigen Zeitpunkt ist und $C_{md\text{-}in}(t+\Delta t)$ eine dimensionslose Relativkonzentration des in die Kokille eingeleiteten geschmolzenen Stahls zu einem gegenwärtigen Zeitpunkt ist.

17. Verfahren nach Anspruch 16, wobei beim Berechnen der dimensionslosen Relativkonzentration der Mitte des Strangs
4±2 auf den Interpolations- und Extrapolationsfaktor (f_{td}) von Gleichung 7 angewandt wird, und
0,7±0,4 auf den Interpolations- und Extrapolationsfaktor (f_{md}) von Gleichung 9 angewandt wird, um die dimensionslose Relativkonzentration ($C_{md\text{-}out\text{-}center}$) der Mitte des Strangs zu berechnen.

18. Verfahren nach Anspruch 16, wobei beim Berechnen der dimensionslosen Relativkonzentration der Oberfläche des Strangs
2,2±0,6 auf den Interpolations- und Extrapolationsfaktor (f_{td}) von Gleichung 7 angewandt wird, und
0,5±0,2 auf den Interpolations- und Extrapolationsfaktor (f_{md}) von Gleichung 9 angewandt wird, um die dimensionslose Relativkonzentration ($C_{md\text{-}out\text{-}surface}$) der Oberfläche des Strangs zu berechnen.

19. Verfahren nach Anspruch 16, wobei eine Flüssigdichte des geschmolzenen Stahls als Dichte(ρ_L)-Wert in den Gleichungen 5, 6 und 8 verwendet wird, und
ein Wert von 7.000 kg/m^3 bis 7.400 kg/m^3 als Dichte des geschmolzenen Stahls verwendet wird.

20. Verfahren nach Anspruch 10, weiterhin umfassend:

Festlegen einer Position des Strangs, bei welcher die dimensionslose Relativkonzentration der Oberfläche des Strangs beginnt erhalten zu werden; und
Festlegen einer Position des Strangs, bei welcher die dimensionslose Relativkonzentration der Mitte des Strangs beginnt erhalten zu werden,
wobei eine Position des Strangs zum Zeitpunkt der Öffnung der nachfolgenden Gießpfanne als die Position festgelegt wird, bei welcher die dimensionslose Relativkonzentration der Oberfläche des Strangs beginnt erhalten zu werden, und
eine Position -4±4 m von der Position des Strangs zum Zeitpunkt der Öffnung der nachfolgenden Gießpfanne als die Position festgelegt wird, bei welcher die dimensionslose Relativkonzentration der Mitte des Strangs beginnt erhalten zu werden.

21. Verfahren nach Anspruch 20, wobei beim Berechnen der Position in der Längsrichtung des Strangs, welche die erhaltene dimensionslose Relativkonzentration der Oberfläche aufweist,
die Position durch Gleichung 10 berechnet wird, in der ein Volumenstrom ($Q_{md\text{-}out}$) des aus der Kokille austretenden geschmolzenen Stahls durch ein Produkt einer Querschnittsfläche (A_{md}) des Strangs und einer Festkörperdichte (ρs) des geschmolzenen Stahls dividiert wird,

[Gleichung 10]

$$L(t+\Delta t)=L(t)+\frac{Q_{md\text{-}out}\times\rho_I}{A_{md}\times\rho_S}\times\Delta t$$

wobei $Q_{md\text{-}out}$ ein Volumenstrom des aus der Kokille austretenden geschmolzenen Stahls ist, A_{md} eine Querschnittsfläche des Strangs ist und ρ_s die Festkörperdichte des geschmolzenen Stahls ist, wobei ein Wert von 7.600 kg/m^3 bis 8.000 kg/m^3 verwendet wird.

22. Verfahren nach Anspruch 21, wobei beim Berechnen der Position in der Längsrichtung des Strangs, welche die erhaltene dimensionslose Relativkonzentration der Mitte aufweist,
eine Position -4±4 m von der Position, welche die erhaltene dimensionslose Relativkonzentration der Oberfläche aufweist, als die Position festgelegt wird, welche die dimensionslose Relativkonzentration der Mitte aufweist.

23. Verfahren nach Anspruch 22, wobei ein Bereich von einem Punkt des Strangs, an welchem die in Echtzeit erhaltene dimensionslose Relativkonzentration der Mitte des Strangs die erste Referenzkonzentration erreicht, bis zu einem Punkt des Strangs, an welchem die in Echtzeit erhaltene dimensionslose Relativkonzentration der Oberfläche des Strangs die zweite Referenzkonzentration erreicht, als der gemischte Abschnitt vorhergesagt wird.

24. Verfahren nach Anspruch 22, weiterhin umfassend:

Festlegen des Punkts des Strangs, an welchem die in Echtzeit erhaltene dimensionslose Relativkonzentration der Mitte des Strangs die erste Referenzkonzentration erreicht, als eine erste Abschneideposition;
Festlegen des Punkts des Strangs, an welchem die in Echtzeit erhaltene dimensionslose Relativkonzentration der Oberfläche des Strangs die zweite Referenzkonzentration erreicht, als eine zweite Abschneideposition; und
Abschneiden des gemischten Abschnitts durch jeweiliges Schneiden des Strangs an der ersten Abschneideposition und der zweiten Abschneideposition.

25. Verfahren nach Anspruch 1 oder 3, wobei das Vorhersagen des gemischten Abschnitts des Strangs und das Abschneiden des vorhergesagten gemischten Abschnitts als Online-Prozess durchgeführt werden.

Revendications

1. Procédé de coulée continue d'aciers hétérogènes, comprenant :

l'acquisition de concentrations relatives sans dimension d'un acier suivant à un acier précédent, respectivement à la surface et à l'intérieur d'une barre de coulée continue en temps réel ;
le calcul de positions dans le sens longitudinal de la barre de coulée ayant les concentrations relatives sans dimension de la surface et de l'intérieur acquises en temps réel ;
la prédiction d'une partie mélangée dans la barre de coulée par la comparaison respective des concentrations relatives sans dimension de la surface et de l'intérieur acquises avec des concentrations de référence ; et
la coupure de la partie mélangée prédite.

2. Procédé selon la revendication 1, dans lequel les positions dans la barre de coulée à partir desquelles les concentrations relatives sans dimension sont acquises sont une surface et un centre dans une direction verticale de la barre de coulée.

3. Procédé de coulée continue d'aciers hétérogènes, comprenant :

l'acquisition de concentrations relatives sans dimension d'un acier suivant à un acier précédent, respectivement en plusieurs positions en hauteur d'une barre de coulée solidifiée et continue coulée à partir d'un moule en temps réel en utilisant des quantités relatives de l'acier précédent et de l'acier suivant dans un panier de coulée et des quantités relatives de l'acier précédent et de l'acier suivant dans le moule ;
le calcule de positions dans un sens longitudinal de la barre de coulée où se trouvent les concentrations relatives sans dimension acquises en temps réel ;
la prédiction d'une partie mélangée de la barre de coulée par la comparaison respective des concentrations relatives sans dimension acquises avec des concentrations de référence ; et
la coupure de la partie mélangée prédite.

4. Procédé selon la revendication 3, dans lequel les plusieurs positions dans le sens de la hauteur de la barre de coulée à partir desquelles les concentrations relatives sans dimension sont acquises comprennent une surface et un centre de la barre de coulée.

5. Procédé selon la revendication 1 ou 3, comprenant en outre la définition des concentrations de référence avant l'acquisition des concentrations relatives sans dimension de l'acier suivant à l'acier précédent dans la barre de coulée continue en temps réel, la définition des concentrations de référence comprenant :

la définition d'une concentration limite la plus basse parmi des concentrations limites supérieures de chaque composant de l'acier précédent comme première concentration de référence ; et
la définition d'une concentration limite la plus haute parmi des concentrations limites inférieures de chaque composant de l'acier précédent comme deuxième concentration de référence.

6. Procédé selon la revendication 5, dans lequel la définition de la première concentration de référence et de la deuxième concentration de référence comprend :

le calcul des concentrations des composants de l'acier précédent comme des concentrations limites inférieures sans dimension et des concentrations limites supérieures sans dimension ;
la définition d'une concentration limite sans dimension la plus basse parmi les concentrations limites supérieures sans dimension de chaque composant de l'acier précédent comme première concentration de référence ;
le calcul des concentrations des composants de l'acier suivant comme des concentrations limites inférieures sans dimension et des concentrations limites supérieures sans dimension ; et
la définition d'une concentration limite sans dimension la plus haute parmi les concentrations limites inférieures sans dimension de chaque composant de l'acier suivant comme deuxième concentration de référence.

7. Procédé selon la revendication 6, dans lequel le calcul des concentrations de chaque composant de l'acier précédent comme concentrations limites inférieures sans dimension et concentrations limites supérieures sans dimension comprend la substitution à une valeur de concentration limite inférieure sans dimension de l'acier précédent d'une valeur de concentration limite supérieure sans dimension de l'acier précédent et la substitution à la valeur de concentration limite supérieure sans dimension de l'acier précédent de la valeur de concentration limite inférieure sans dimension de l'acier précédent quand la concentration limite inférieure sans dimension de l'acier précédent est supérieure à la concentration limite supérieure sans dimension de l'acier précédent ;
le calcul des concentrations de chaque composant de l'acier suivant comme les concentrations limites inférieures sans dimension et les concentrations limites supérieures sans dimension comprend la substitution à une valeur de concentration limite inférieure sans dimension de l'acier suivant d'une valeur de concentration limite supérieure sans dimension de l'acier suivant et la substitution à la valeur de concentration limite supérieure sans dimension de l'acier suivant de la valeur de concentration limite inférieure sans dimension de l'acier suivant quand la concentration limite inférieure sans dimension de l'acier suivant est supérieure à la concentration limite supérieure sans dimension de l'acier suivant.

8. Procédé selon la revendication 2 ou 4, dans lequel il est déterminé que la barre de coulée est dans un état mélangé quand au moins une concentration relative sans dimension parmi les concentrations relatives sans dimension acquises à la surface et au centre s'écarte de la concentration de référence, et
une position dans le sens longitudinal de la barre de coulée dans laquelle au moins une concentration relative sans dimension parmi les concentrations relatives sans dimension acquises à la surface et au centre s'écarte de la concentration de référence est identifiée comme la partie mélangée.

9. Procédé selon la revendication 8, dans lequel une position dans le sens longitudinal de la barre de coulée dans laquelle la concentration relative sans dimension acquise au centre atteint la concentration de référence est identifiée comme un point de début de la partie mélangée et
une position dans le sens longitudinal de la barre de coulée dans laquelle la concentration relative sans dimension acquise à la surface atteint la concentration est identifiée comme le point de fin de la partie mélangée.

10. Procédé selon la revendication 2 ou 4, comprenant en outre :

la réception de données sur une quantité résiduelle d'acier en fusion dans le panier de coulée, la vitesse de coulée et les concentrations de l'acier précédent et de l'acier suivant en ligne et l'enregistrement des données ; et
la détection d'un signal d'ouverture de la poche de coulée suivante avant l'obtention des concentrations relatives sans dimension de l'acier suivant à l'acier précédent.

11. Procédé selon la revendication 10, comprenant en outre :

l'acquisition de concentrations relatives sans dimension acquises à la surface et au centre de la barre de coulée en temps réel à partir du moment de réception du signal d'ouverture de la poche de coulée suivante, et le comptage d'un temps d'acquisition de la concentration sans dimension à partir du moment de détection du signal d'ouverture de la poche de coulée suivante à comparer avec un temps de référence en temps réel ;

la comparaison de la concentration relative sans dimension acquise au centre avec la première concentration de référence et la comparaison de la concentration relative sans dimension obtenue à la surface avec la deuxième concentration de référence quand le temps d'acquisition de la concentration sans dimension est égal ou inférieur au temps de référence ; et
l'arrêt de l'acquisition des concentrations relatives sans dimension à la surface et au centre de la barre de coulée quand le temps d'acquisition de la concentration est supérieur au temps de référence.

12. Procédé selon la revendication 11, comprenant en outre :

la détermination du fait qu'un type entre l'acier précédent et l'acier suivant est ou non un type inclus dans un tableau de séparation d'aciers hétérogènes prédéfini ;
la coupe de la barre de coulée à une longueur de coupe du type d'acier hétérogène correspondant quand le type entre l'acier précédent et l'acier suivant soumis à une opération en cours est le type figurant dans le tableau de séparation d'aciers hétérogènes prédéfini ; et
la coupe de la barre de coulée à une longueur de coupe prédéterminée quand le type entre l'acier précédent et l'acier suivant soumis à l'opération en cours ne figure pas dans le tableau de séparation d'aciers hétérogènes prédéfini, après l'arrêt de l'acquisition des concentrations relatives sans dimension à la surface et au centre de la barre de coulée.

13. Procédé selon la revendication 10, dans lequel la détection du signal d'ouverture de la poche de coulée suivante comprend :

l'émission d'un signal d'ouverture de poche de coulée virtuelle,
la détection d'un poids du panier de coulée en temps réel, en millisecondes (ms) à partir du moment d'émission du signal d'ouverture de poche de coulée virtuelle,
le calcul du poids du panier de coulée détecté en millisecondes (ms) comme le poids moyen du panier de coulée à des intervalles de temps prédéterminés en secondes (s) et
le réglage d'un temps d'ouverture de la poche de coulée suivante à l'aide d'un temps d'augmentation continue du poids moyen du panier de coulée.

14. Procédé selon la revendication 13, dans lequel, quand $W_{td}(t)$ est un poids d'une quantité d'acier résiduel dans le panier de coulée à l'instant présent et $W_{dt}(t-\Delta t)$ est un poids d'une quantité d'acier résiduel dans le panier de coulée à un instant antérieur,
$t-2^*\Delta t$ est déterminé comme le moment d'ouverture de la poche de coulée suivante quand $W_{td}(t) - W_{td}(t-\Delta t)$ et $W_{td}(t) - W_{td}(t-2^*\Delta t)$ sont tous deux supérieurs ou égaux à 0,
les concentrations relatives sans dimension à la surface et au centre de la barre de coulée sont obtenues à partir de $t-2^*\Delta t$ et
la quantité d'acier résiduel dans le panier de coulée et la vitesse de coulée sont enregistrées à partir de $t-4^*\Delta t$.

15. Procédé selon la revendication 2 ou 4, dans lequel l'obtention des concentrations relatives sans dimension de l'acier suivant à l'acier précédent à la surface et au centre de la barre de coulée comprend :

le calcul d'un débit volumique à l'entrée (Q_{td-in}) de l'acier suivant dans le panier de coulée ;
le calcul d'une concentration relative sans dimension moyenne ($C_{td-ave}(t+\Delta t)$) de l'acier en fusion dans le panier de coulée à un instant présent à l'aide du débit volumique à l'entrée (Q_{td-in}) de l'acier suivant dans le panier de coulée ;
le calcul d'une concentration relative sans dimension ($C_{td-out}(t+\Delta t)$) de l'acier en fusion sortant du panier de coulée à un instant présent à l'aide de la concentration relative sans dimension moyenne ($C_{td-ave}(t+\Delta t)$) de l'acier en fusion dans le panier de coulée à un instant présent ;
le calcul d'une concentration relative sans dimension moyenne ($C_{md-ave}(t+\Delta t)$) de l'acier en fusion dans le moule à un instant présent à l'aide de la concentration relative sans dimension ($C_{td-out}(t+\Delta t)$) de l'acier en fusion sortant du panier de coulée à un instant présent ; et
le calcul d'une concentration relative sans dimension ($C_{md-out}(t+\Delta t)$) de la barre de coulée sortant du moule à un instant présent à l'aide de la concentration relative sans dimension moyenne ($C_{md-ave}(t+\Delta t)$) de l'acier en fusion dans le moule à un instant présent et d'une concentration relative sans dimension ($C_{md-in}(t+\Delta t)$) de l'acier en fusion introduit dans le moule à un instant présent.

16. Procédé selon la revendication 15, dans lequel le débit volumique à l'entrée (Q_{td-in}) de l'acier suivant dans le panier de coulée est calculé selon l'équation 5,

[Équation 5]

$$Q_{td\text{-}in} = \frac{W_{td}(t+\Delta t) - W_{td}(t)}{\Delta t \times \rho_L} + Q_{td\text{-}out}$$

où $W_{td}(t)$ est un poids total de l'acier en fusion dans le panier de coulée à un instant antérieur, $W_{td}(t+\Delta t)$ est un poids total de l'acier en fusion dans le panier de coulée à un instant présent, $Q_{td\text{-}out}$ est un débit volumique de l'acier en fusion sortant du panier de coulée et ρ_L est la densité à l'état liquide de l'acier en fusion,
la concentration moyenne ($C_{td\text{-}ave}(t+\Delta t)$) de l'acier en fusion dans le panier de coulée à un instant présent est calculée selon l'équation 6,

[Équation 6]

$$C_{td\text{-}ave}(t+\Delta t) = \frac{W_{td}(t) \times C_{td\text{-}ave}(t) + Q_{td\text{-}in}(t) \times \Delta t \times \rho_L \times C_{td\text{-}in}(t)}{W_{td}(t+\Delta t)} - \frac{Q_{td\text{-}out}(t) \times \Delta t \times \rho_L \times C_{td\text{-}out}(t)}{W_{td}(t+\Delta t)}$$

où $C_{td\text{-}ave}(t)$ est une concentration relative sans dimension moyenne de l'acier en fusion dans le panier de coulée à un instant antérieur, $Q_{td\text{-}in}(t)$ est un débit volumique à l'entrée de l'acier en fusion introduit dans le panier de coulée à un instant antérieur, $C_{td\text{-}in}(t)$ est une concentration d'entrée (concentration relative sans dimension) de l'acier suivant dans le panier de coulée à un instant antérieur, $Q_{td\text{-}out}(t)$ est un débit volumique de l'acier en fusion sortant du panier de coulée à un instant antérieur, $C_{td\text{-}out}(t)$ est une concentration (concentration relative sans dimension) de l'acier en fusion sortant du panier de coulée à un instant antérieur et ρ_L est la densité à l'état liquide de l'acier en fusion,
la concentration (($C_{td\text{-}out}(t+\Delta t)$) de l'acier en fusion sortant du panier de coulée à un instant présent est calculée selon l'équation 7,

[Équation 7]

$$C_{td\text{-}out}(t+\Delta t) = f_{td} \times C_{td\text{-}ave}(t+\Delta t) + (1 - f_{td}) \times C_{td\text{-}in}(t+\Delta t)$$

où f_{td} est un facteur d'interpolation et d'extrapolation du panier de coulée, $C_{td\text{-}ave}(t+\Delta t)$ est une concentration relative sans dimension moyenne de l'acier en fusion dans le panier de coulée à un instant présent et $C_{td\text{-}in}(t+\Delta t)$ est une concentration relative sans dimension de l'acier en fusion introduit dans le panier de coulée à un instant présent,
la concentration moyenne ($C_{md\text{-}ave}(t+\Delta t)$) de l'acier en fusion dans le moule à un instant présent est calculée selon l'équation 8,

[Équation 8]

$$C_{md\text{-}ave}(t+\Delta t) = \frac{W_{md}(t) \times C_{md\text{-}ave}(t) + Q_{md\text{-}in}(t) \times \Delta t \times \rho_L \times C_{md\text{-}in}(t)}{W_{md}(t+\Delta t)} - \frac{Q_{md\text{-}out}(t) \times \Delta t \times \rho_L \times C_{md\text{-}out}(t)}{W_{md}(t+\Delta t)}$$

où $W_{md}(t)$ est un poids total de l'acier en fusion dans le moule à un instant antérieur, $C_{md\text{-}ave}(t)$ est une concentration relative sans dimension moyenne de l'acier en fusion dans le moule à un instant antérieur, $Q_{md\text{-}in}(t)$ est un débit volumique à l'entrée de l'acier en fusion dans le moule à un instant antérieur, $C_{md\text{-}in}(t)$ est une concentration à l'entrée (concentration relative sans dimension) de l'acier en fusion dans le moule à un instant antérieur, $W_{md}(t+\Delta t)$ est un poids total de l'acier en fusion dans le moule à un instant présent, $Q_{md\text{-}out}(t)$ est un débit volumique de l'acier en fusion sortant du moule, $C_{md\text{-}out}(t)$ est une concentration relative sans dimension de la barre de coulée sortant du moule à un instant antérieur et ρ_L est la densité à l'état liquide de l'acier en fusion, et
la concentration ($C_{md\text{-}out}(t+\Delta t)$) de la barre de coulée sortant du moule à un instant présent est calculée selon l'équation 9,

[Équation 9] $$C_{md\text{-}out}(t+\Delta t)=f_{md}\times C_{md\text{-}ave}(t+\Delta t)+(1-f_{md})\times C_{md\text{-}in}(t+\Delta t)$$

où f_{md} est un facteur d'interpolation et d'extrapolation du moule, $C_{md\text{-}ave}(t+\Delta t)$ est une concentration relative sans dimension moyenne de l'acier en fusion dans le moule à un instant présent et $C_{md\text{-}in}(t+\Delta t)$ est une concentration relative sans dimension de l'acier en fusion introduit dans le moule à un instant présent.

17. Procédé selon la revendication 16 dans lequel, dans le calcul de la concentration relative sans dimension du centre de la barre de coulée,
4 ± 2 est appliqué au facteur d'interpolation et d'extrapolation (f_{td}) de l'équation 7 et
$0{,}7\pm0{,}4$ est appliqué au facteur d'interpolation et d'extrapolation (f_{md}) de l'équation 9 pour calculer la concentration relative sans dimension ($C_{md\text{-}out\text{-}center}$) au centre de la barre de coulée.

18. Procédé selon la revendication 16, dans lequel, dans le calcul de la concentration relative sans dimension du centre de la barre de coulée,
$2{,}2\pm0{,}6$ est appliqué au facteur d'interpolation et d'extrapolation (f_{td}) de l'équation 7 et
$0{,}5\pm0{,}2$ est appliqué au facteur d'interpolation et d'extrapolation (f_{md}) de l'équation 9 pour calculer la concentration relative sans dimension ($C_{md\text{-}out\text{-}surface}$) à la surface de la barre de coulée.

19. Procédé selon la revendication 16, dans lequel une densité à l'état liquide de l'acier en fusion est utilisée comme valeur de densité (ρ_L) dans les équations 5, 6 et 8, et
une valeur de 7000 kg/m^3 à 7400 kg/m^3 est utilisée comme densité de l'acier en fusion.

20. Procédé selon la revendication 10, comprenant en outre :

le réglage d'une position dans la barre de coulée dans laquelle la concentration relative sans dimension de la surface de la barre de coulée commence à être obtenue et
le réglage d'une position dans la barre de coulée dans laquelle la concentration relative sans dimension du centre de la barre de coulée commence à être obtenue,
une position dans la barre de coulée au moment de l'ouverture de la poche de coulée suivante étant réglée à la position dans laquelle la concentration relative sans dimension à la surface de la barre de coulée commence à être obtenue, et
une position à -4 ± 4 m de la position dans la barre de coulée au moment de l'ouverture de la poche de coulée suivante est réglée à la position dans laquelle la concentration relative sans dimension au centre de la barre de coulée commence à être obtenue.

21. Procédé selon la revendication 20 dans lequel, dans le calcul de la position dans le sens longitudinal de la barre de coulée ayant la concentration relative sans dimension obtenue de la surface, la position est calculée selon l'équation 10 dans laquelle un débit volumique ($Q_{md\text{-}out}$) de l'acier en fusion sortant du moule est divisé par le produit d'une aire de section (A_{md}) de la barre de coulée et de la densité à l'état solide (ρ_s) de l'acier en fusion,

[équation 10] $$L(t+\Delta t)=L(t)+\frac{Q_{md\text{-}out}\times\rho_L}{A_{md}\times\rho_S}\times\Delta t$$

où $Q_{md\text{-}out}$ est un débit volumique de l'acier en fusion sortant du moule, A_{md} est une aire de section de la barre de coulée et ρ_s est la densité à l'état solide de l'acier en fusion, pour laquelle une valeur de 7600 kg/m^3 à 8000 kg/m^3 est utilisée.

22. Procédé selon la revendication 21 dans lequel, dans le calcul de la position dans le sens longitudinal de la barre de coulée ayant la concentration relative sans dimension obtenue au centre, une position à -4 ± 4 m de la position ayant la concentration relative sans dimension obtenue à la surface est réglée comme position ayant la concentration relative sans dimension au centre.

23. Procédé selon la revendication 22, dans lequel une région allant d'un point de la barre de coulée auquel la concentration relative sans dimension au centre de la barre de coulée obtenue en temps réel atteint la première concentration de référence à un point de la barre de coulée auquel la concentration relative sans dimension au centre de la barre de coulée obtenue en temps réel atteint la deuxième concentration de référence est prédite comme la partie mélangée.

24. Procédé selon la revendication 22, comprenant en outre :

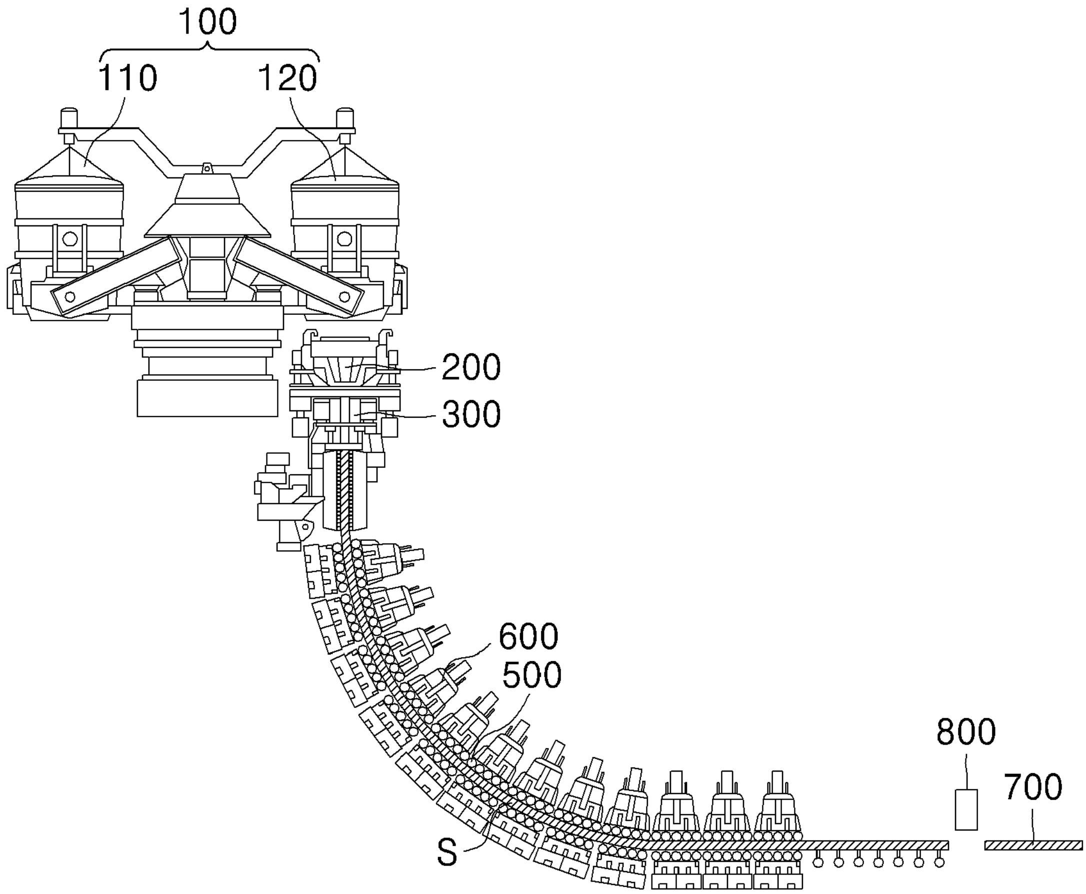
le réglage du point de la barre de coulée auquel la concentration relative sans dimension au centre de la barre de coulée obtenue en temps réel atteint la première concentration de référence comme première position de coupure ;

le réglage du point de la barre de coulée auquel la concentration relative sans dimension à la surface de la barre de coulée obtenue en temps réel atteint la deuxième concentration de référence comme une deuxième position de coupure ; et

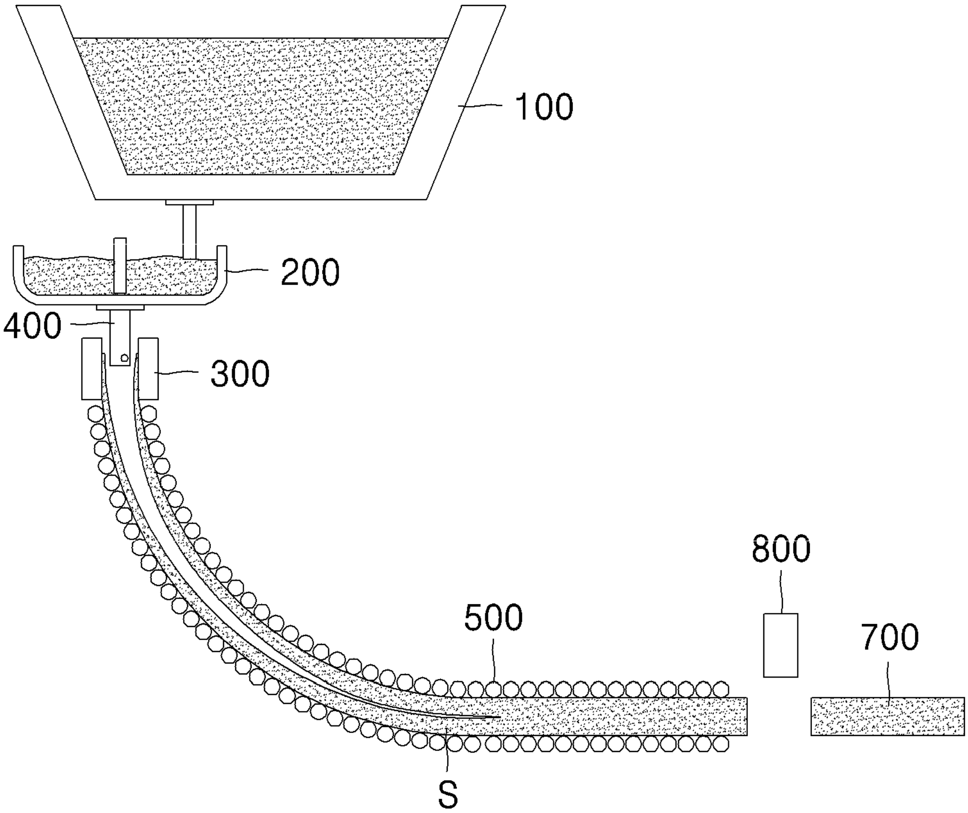
la coupure de la partie mélangée en coupant la barre de coulée respectivement dans la première position de coupure et la deuxième position de coupure.

25. Procédé selon la revendication 1 ou 3, dans lequel la prédiction de la partie mélangée de la barre de coulée et la coupure de la partie mélangée prédite sont réalisées comme un processus en ligne.

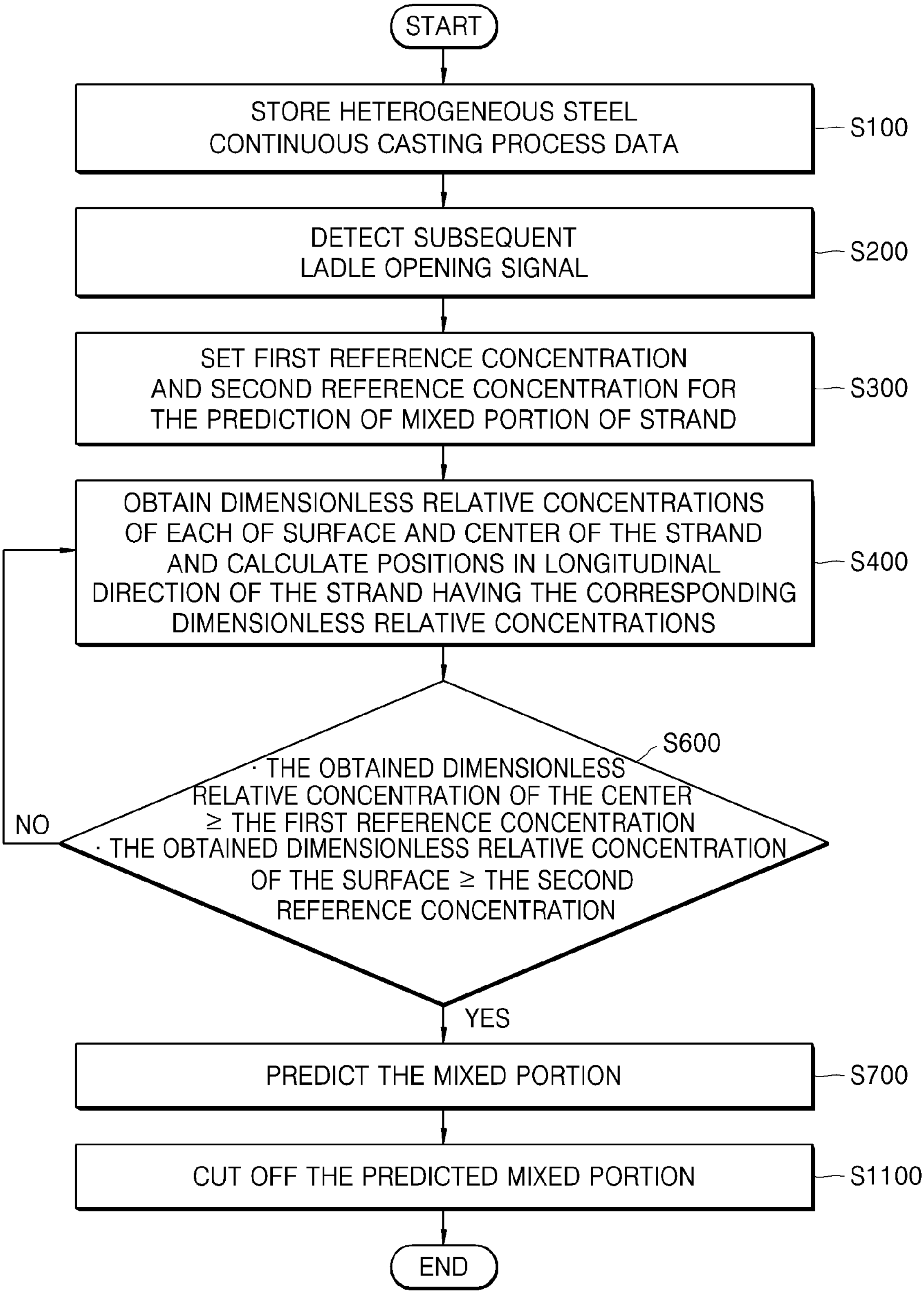
[Fig.1]



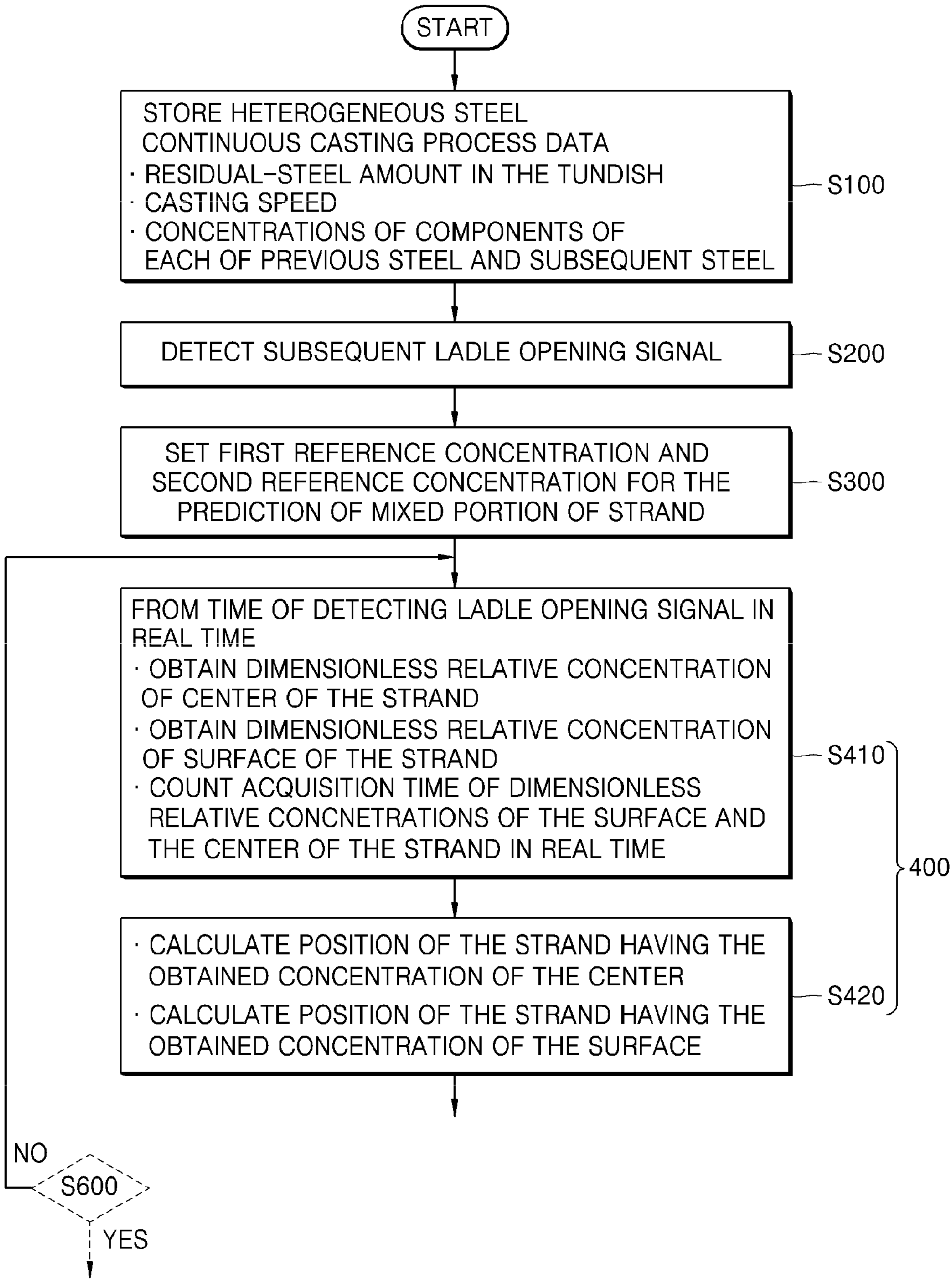
[Fig.2]



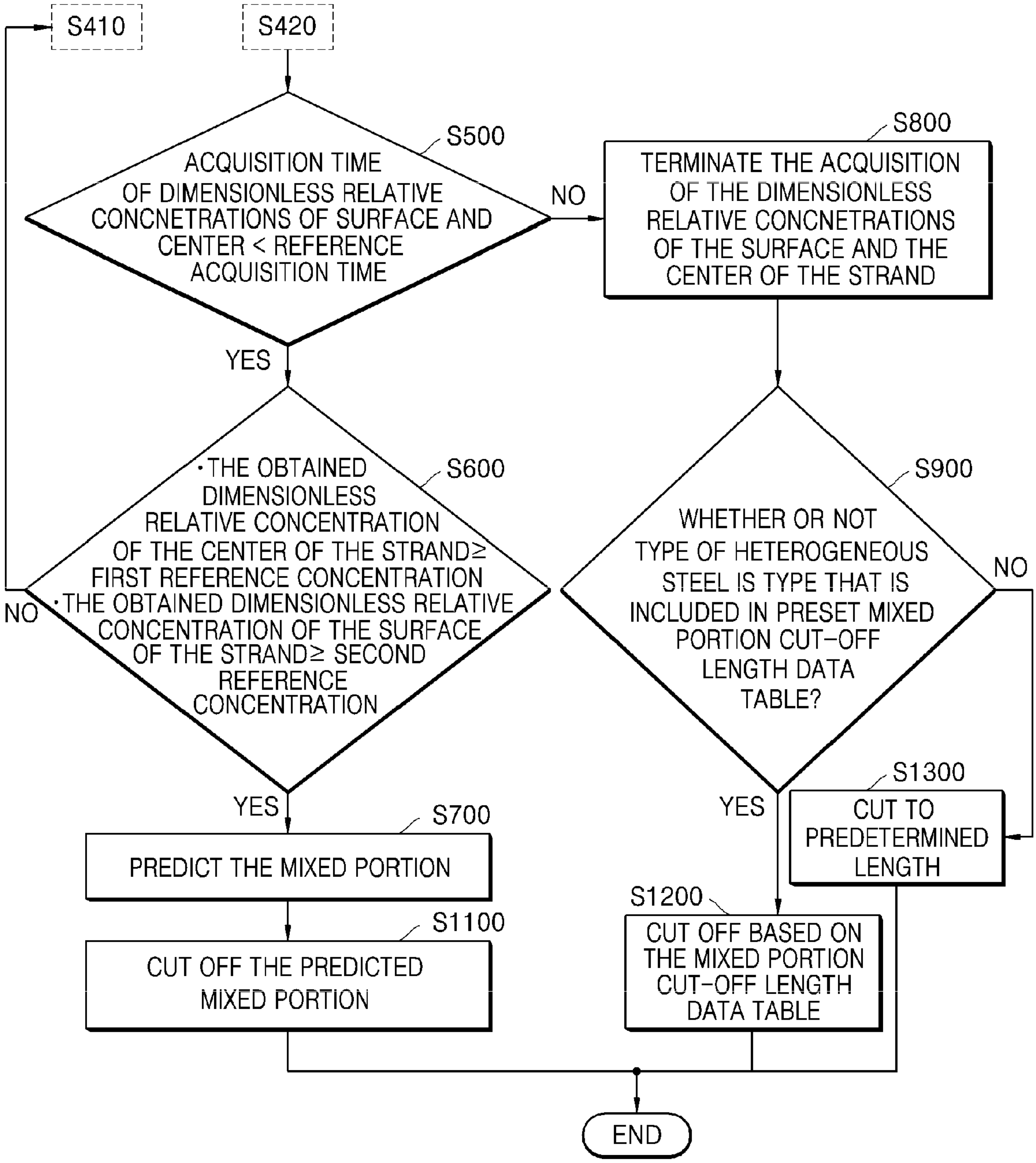
[Fig.3]


START
STORE HETEROGENEOUS STEEL CONTINUOUS CASTING PROCESS DATA
S100
DETECT SUBSEQUENT LADLE OPENING SIGNAL
S200
SET FIRST REFERENCE CONCENTRATION AND SECOND REFERENCE CONCENTRATION FOR THE PREDICTION OF MIXED PORTION OF STRAND
S300
OBTAIN DIMENSIONLESS RELATIVE CONCENTRATIONS OF EACH OF SURFACE AND CENTER OF THE STRAND AND CALCULATE POSITIONS IN LONGITUDINAL DIRECTION OF THE STRAND HAVING THE CORRESPONDING DIMENSIONLESS RELATIVE CONCENTRATIONS
S400
S600
· THE OBTAINED DIMENSIONLESS RELATIVE CONCENTRATION OF THE CENTER ≥ THE FIRST REFERENCE CONCENTRATION
· THE OBTAINED DIMENSIONLESS RELATIVE CONCENTRATION OF THE SURFACE ≥ THE SECOND REFERENCE CONCENTRATION
NO
YES
PREDICT THE MIXED PORTION
S700
CUT OFF THE PREDICTED MIXED PORTION
S1100
END

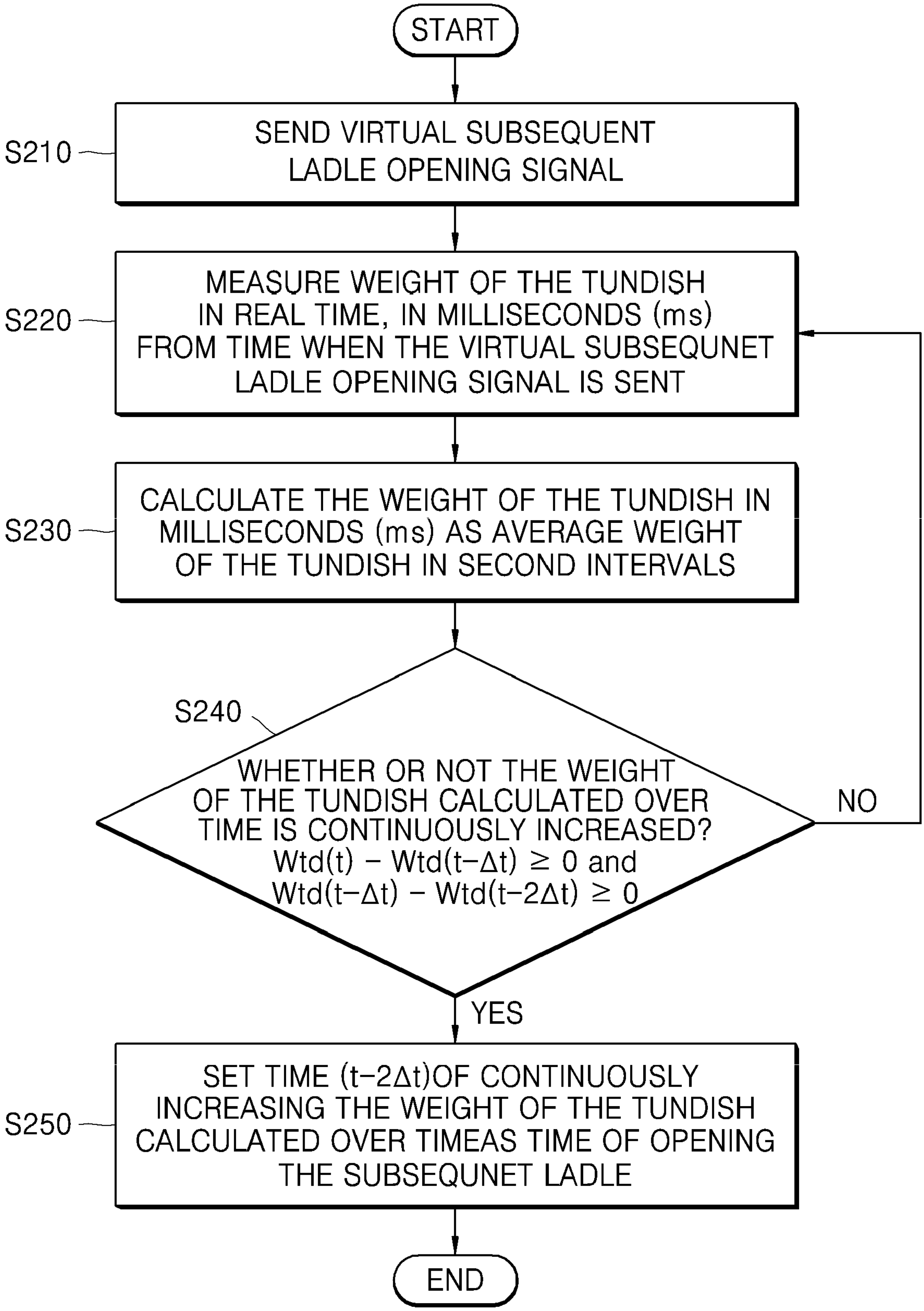
[Fig.4]


START
STORE HETEROGENEOUS STEEL CONTINUOUS CASTING PROCESS DATA
· RESIDUAL-STEEL AMOUNT IN THE TUNDISH
· CASTING SPEED
· CONCENTRATIONS OF COMPONENTS OF EACH OF PREVIOUS STEEL AND SUBSEQUENT STEEL
S100
DETECT SUBSEQUENT LADLE OPENING SIGNAL
S200
SET FIRST REFERENCE CONCENTRATION AND SECOND REFERENCE CONCENTRATION FOR THE PREDICTION OF MIXED PORTION OF STRAND
S300
FROM TIME OF DETECTING LADLE OPENING SIGNAL IN REAL TIME
· OBTAIN DIMENSIONLESS RELATIVE CONCENTRATION OF CENTER OF THE STRAND
· OBTAIN DIMENSIONLESS RELATIVE CONCENTRATION OF SURFACE OF THE STRAND
· COUNT ACQUISITION TIME OF DIMENSIONLESS RELATIVE CONCNETRATIONS OF THE SURFACE AND THE CENTER OF THE STRAND IN REAL TIME
S410
400
· CALCULATE POSITION OF THE STRAND HAVING THE OBTAINED CONCENTRATION OF THE CENTER
· CALCULATE POSITION OF THE STRAND HAVING THE OBTAINED CONCENTRATION OF THE SURFACE
S420
NO
S600
YES

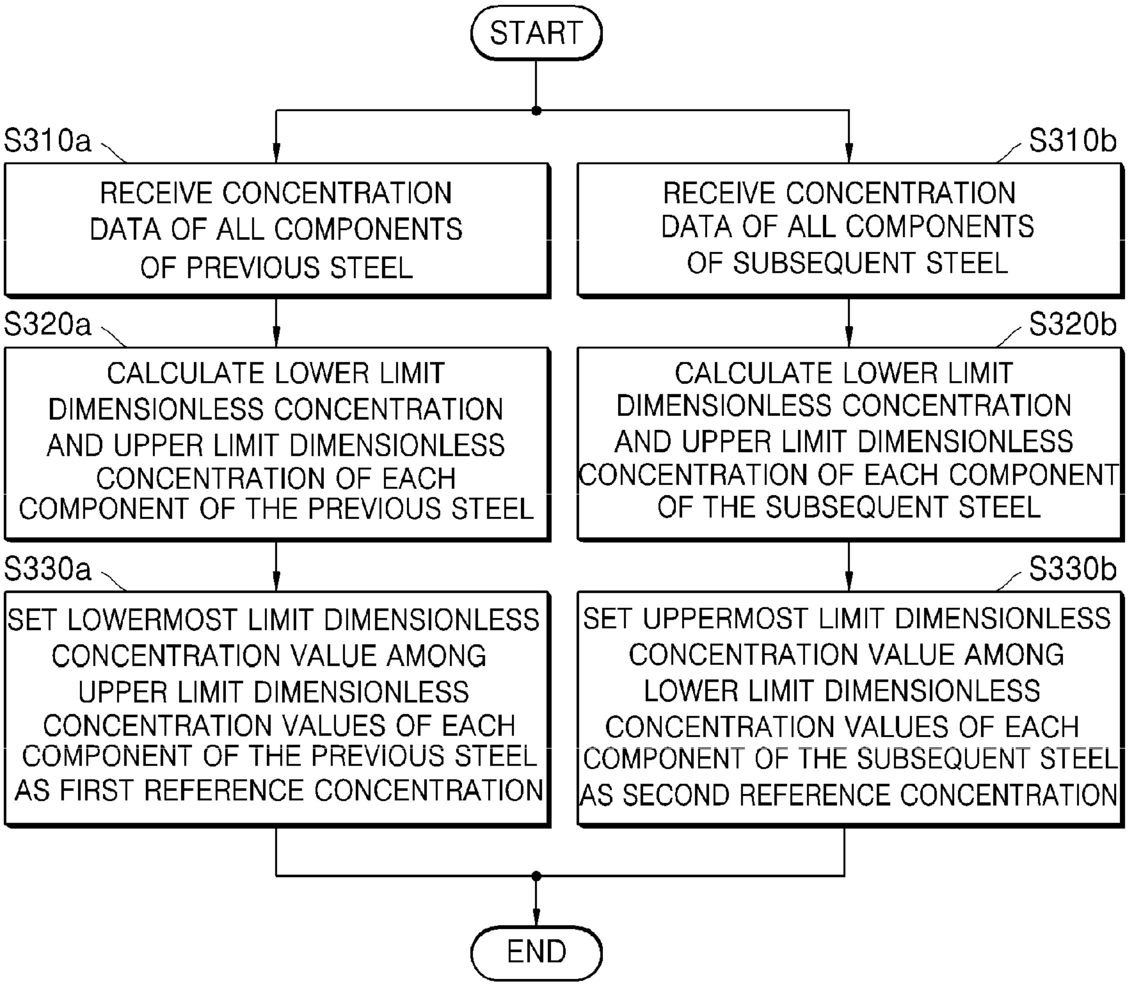
[Fig.5]


S410
S420
ACQUISITION TIME OF DIMENSIONLESS RELATIVE CONCNETRATIONS OF SURFACE AND CENTER < REFERENCE ACQUISITION TIME
S500
NO
S800
TERMINATE THE ACQUISITION OF THE DIMENSIONLESS RELATIVE CONCNETRATIONS OF THE SURFACE AND THE CENTER OF THE STRAND
YES
·THE OBTAINED DIMENSIONLESS RELATIVE CONCENTRATION OF THE CENTER OF THE STRAND≥ FIRST REFERENCE CONCENTRATION
·THE OBTAINED DIMENSIONLESS RELATIVE CONCENTRATION OF THE SURFACE OF THE STRAND≥ SECOND REFERENCE CONCENTRATION
S600
NO
WHETHER OR NOT TYPE OF HETEROGENEOUS STEEL IS TYPE THAT IS INCLUDED IN PRESET MIXED PORTION CUT-OFF LENGTH DATA TABLE?
S900
NO
YES
S700
PREDICT THE MIXED PORTION
S1100
CUT OFF THE PREDICTED MIXED PORTION
YES
S1300
CUT TO PREDETERMINED LENGTH
S1200
CUT OFF BASED ON THE MIXED PORTION CUT-OFF LENGTH DATA TABLE
END

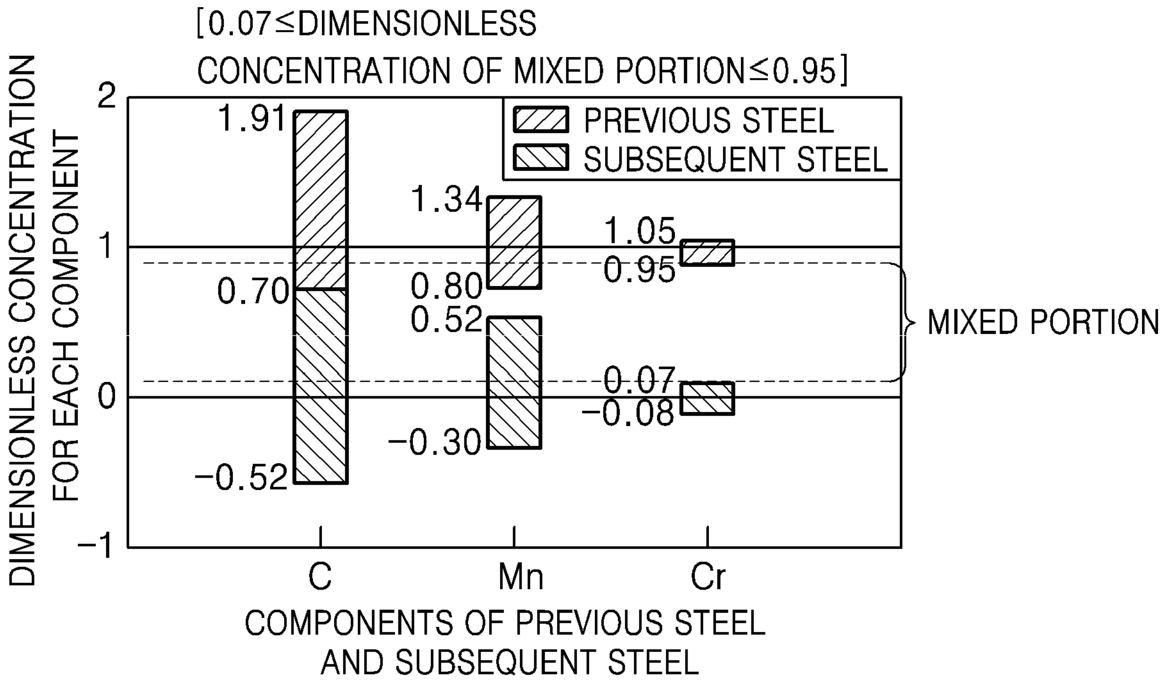
[Fig.6]


START
S210
SEND VIRTUAL SUBSEQUENT LADLE OPENING SIGNAL
S220
MEASURE WEIGHT OF THE TUNDISH IN REAL TIME, IN MILLISECONDS (ms) FROM TIME WHEN THE VIRTUAL SUBSEQUNET LADLE OPENING SIGNAL IS SENT
S230
CALCULATE THE WEIGHT OF THE TUNDISH IN MILLISECONDS (ms) AS AVERAGE WEIGHT OF THE TUNDISH IN SECOND INTERVALS
S240
WHETHER OR NOT THE WEIGHT OF THE TUNDISH CALCULATED OVER TIME IS CONTINUOUSLY INCREASED?
Wtd(t) − Wtd(t−Δt) ≥ 0 and
Wtd(t−Δt) − Wtd(t−2Δt) ≥ 0
NO
YES
S250
SET TIME (t−2Δt)OF CONTINUOUSLY INCREASING THE WEIGHT OF THE TUNDISH CALCULATED OVER TIMEAS TIME OF OPENING THE SUBSEQUNET LADLE
END

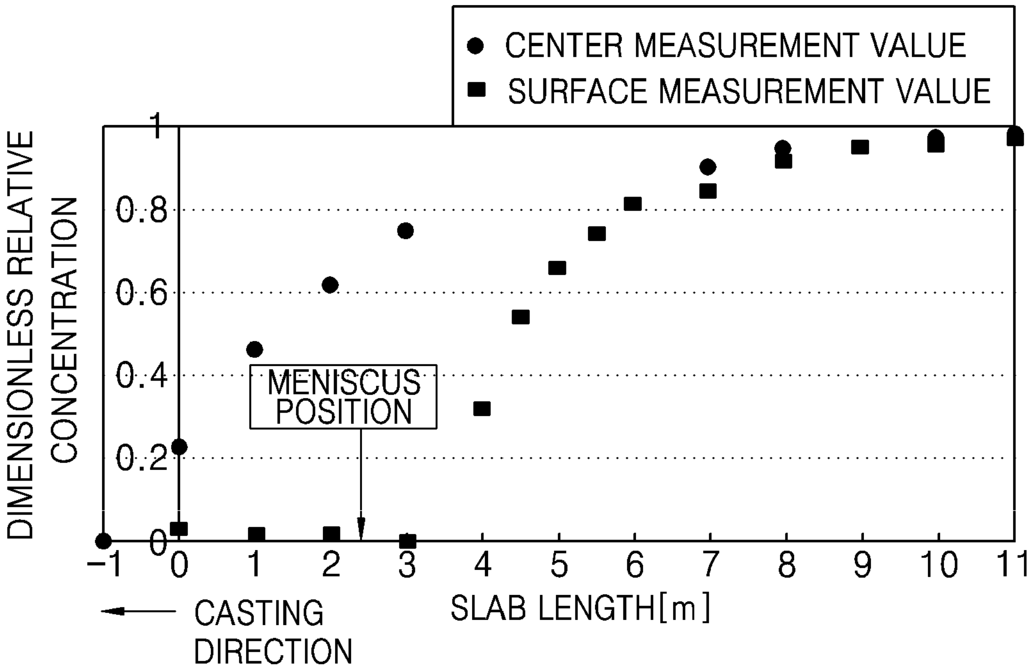
[Fig.7]


START
S310a
RECEIVE CONCENTRATION DATA OF ALL COMPONENTS OF PREVIOUS STEEL
S310b
RECEIVE CONCENTRATION DATA OF ALL COMPONENTS OF SUBSEQUENT STEEL
S320a
CALCULATE LOWER LIMIT DIMENSIONLESS CONCENTRATION AND UPPER LIMIT DIMENSIONLESS CONCENTRATION OF EACH COMPONENT OF THE PREVIOUS STEEL
S320b
CALCULATE LOWER LIMIT DIMENSIONLESS CONCENTRATION AND UPPER LIMIT DIMENSIONLESS CONCENTRATION OF EACH COMPONENT OF THE SUBSEQUENT STEEL
S330a
SET LOWERMOST LIMIT DIMENSIONLESS CONCENTRATION VALUE AMONG UPPER LIMIT DIMENSIONLESS CONCENTRATION VALUES OF EACH COMPONENT OF THE PREVIOUS STEEL AS FIRST REFERENCE CONCENTRATION
S330b
SET UPPERMOST LIMIT DIMENSIONLESS CONCENTRATION VALUE AMONG LOWER LIMIT DIMENSIONLESS CONCENTRATION VALUES OF EACH COMPONENT OF THE SUBSEQUENT STEEL AS SECOND REFERENCE CONCENTRATION
END

[Fig.8]

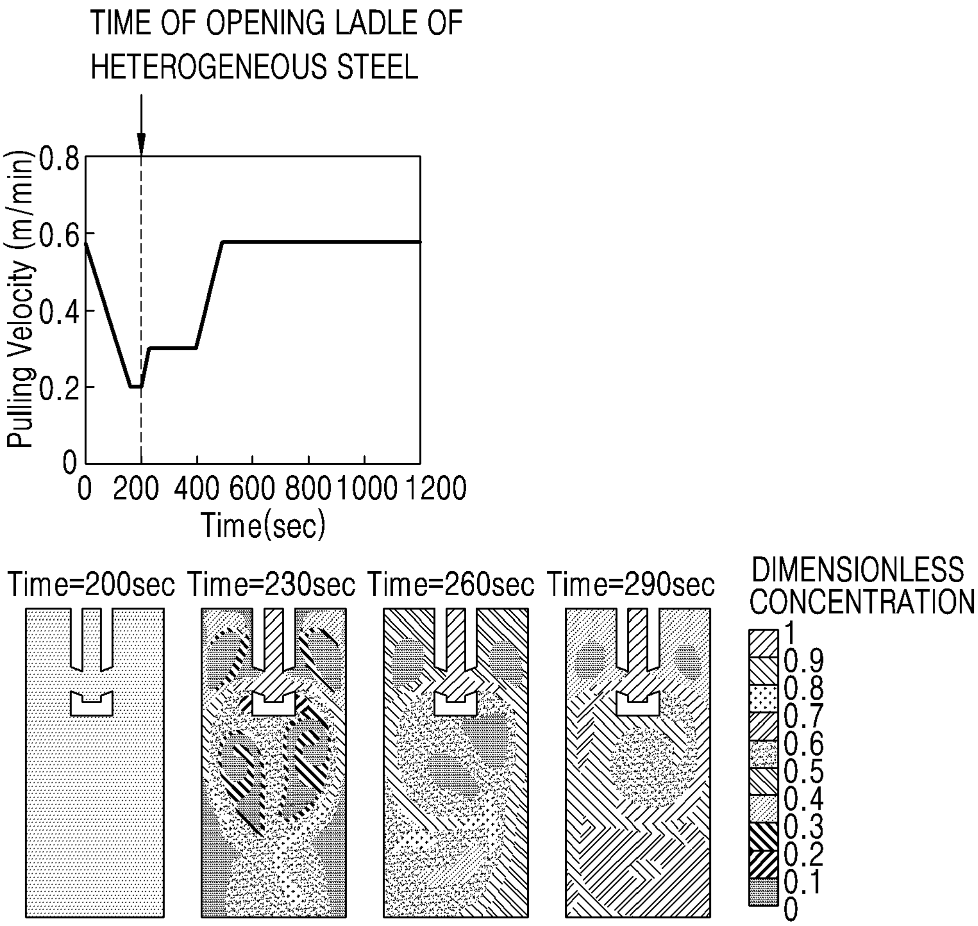

[0.07≤DIMENSIONLESS
CONCENTRATION OF MIXED PORTION≤0.95]
DIMENSIONLESS CONCENTRATION
FOR EACH COMPONENT
2
1
0
−1
PREVIOUS STEEL
SUBSEQUENT STEEL
1.91
0.70
−0.52
1.34
0.80
0.52
−0.30
1.05
0.95
0.07
−0.08
MIXED PORTION
C
Mn
Cr
COMPONENTS OF PREVIOUS STEEL
AND SUBSEQUENT STEEL

[Fig.9]

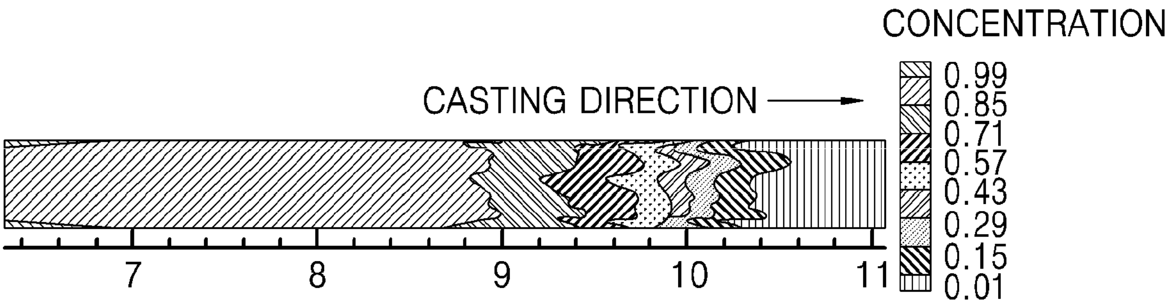


ANALYSIS RESULT OF Cr COMPONENT OF MIXED PORTION

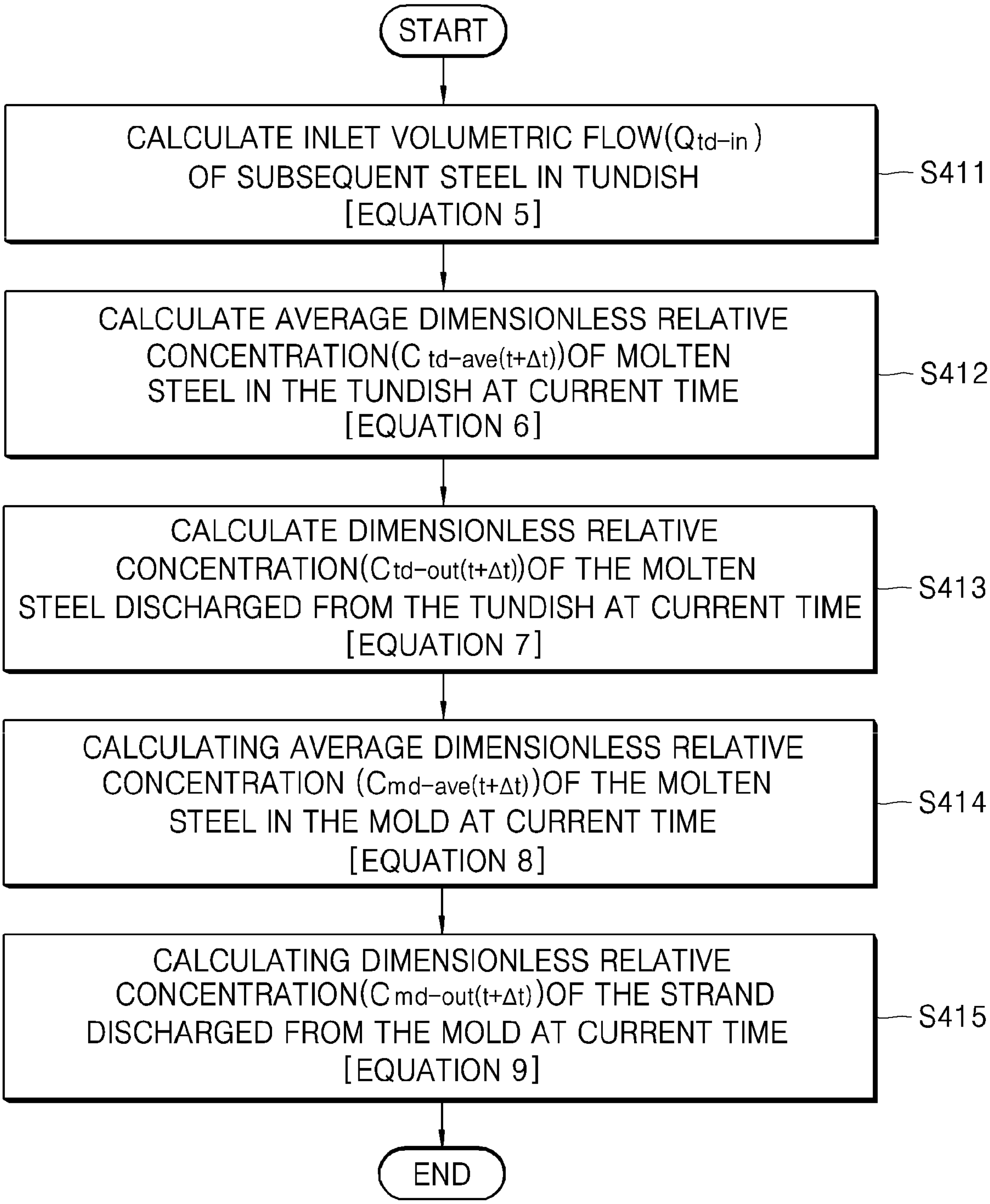
[Fig.10]


TIME OF OPENING LADLE OF
HETEROGENEOUS STEEL
Pulling Velocity (m/min)
0.8
0.6
0.4
0.2
0
0 200 400 600 800 1000 1200
Time(sec)
Time=200sec
Time=230sec
Time=260sec
Time=290sec
DIMENSIONLESS
CONCENTRATION
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

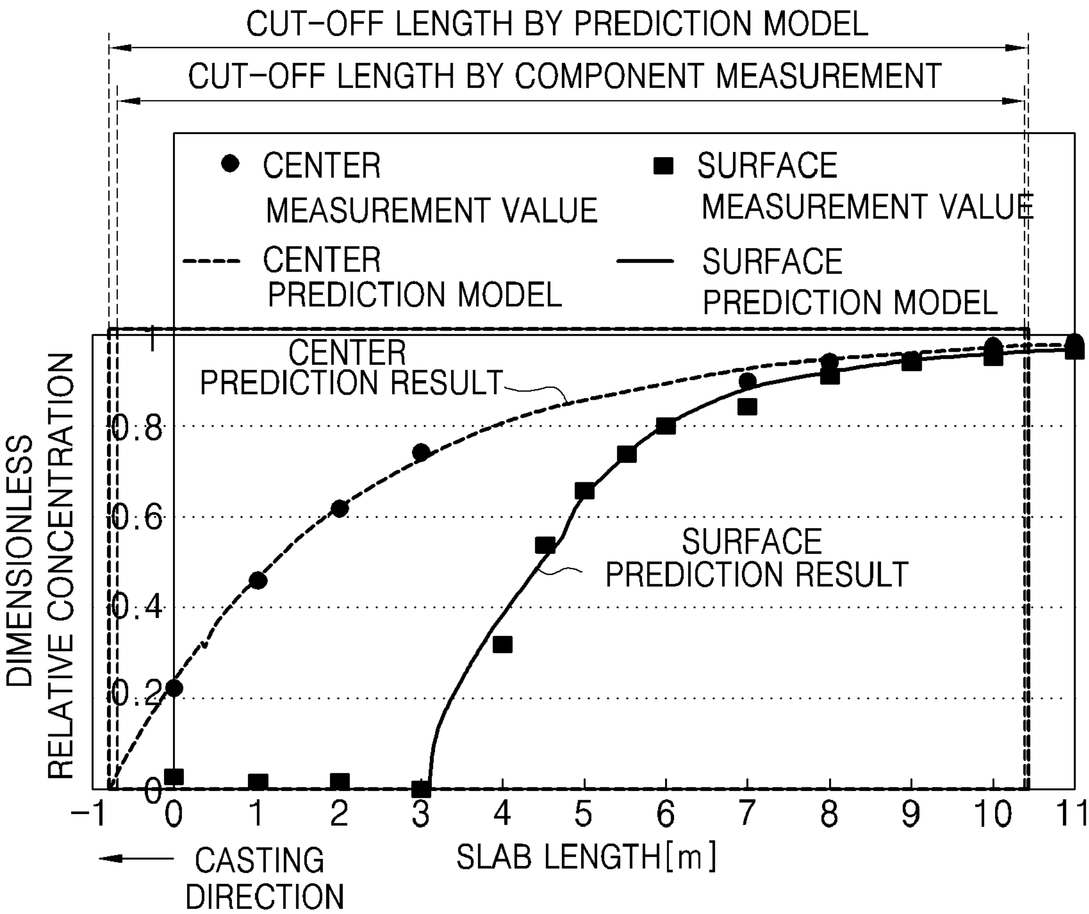
[Fig.11]


CONCENTRATION
0.99
0.85
0.71
0.57
0.43
0.29
0.15
0.01
CASTING DIRECTION
7
8
9
10
11

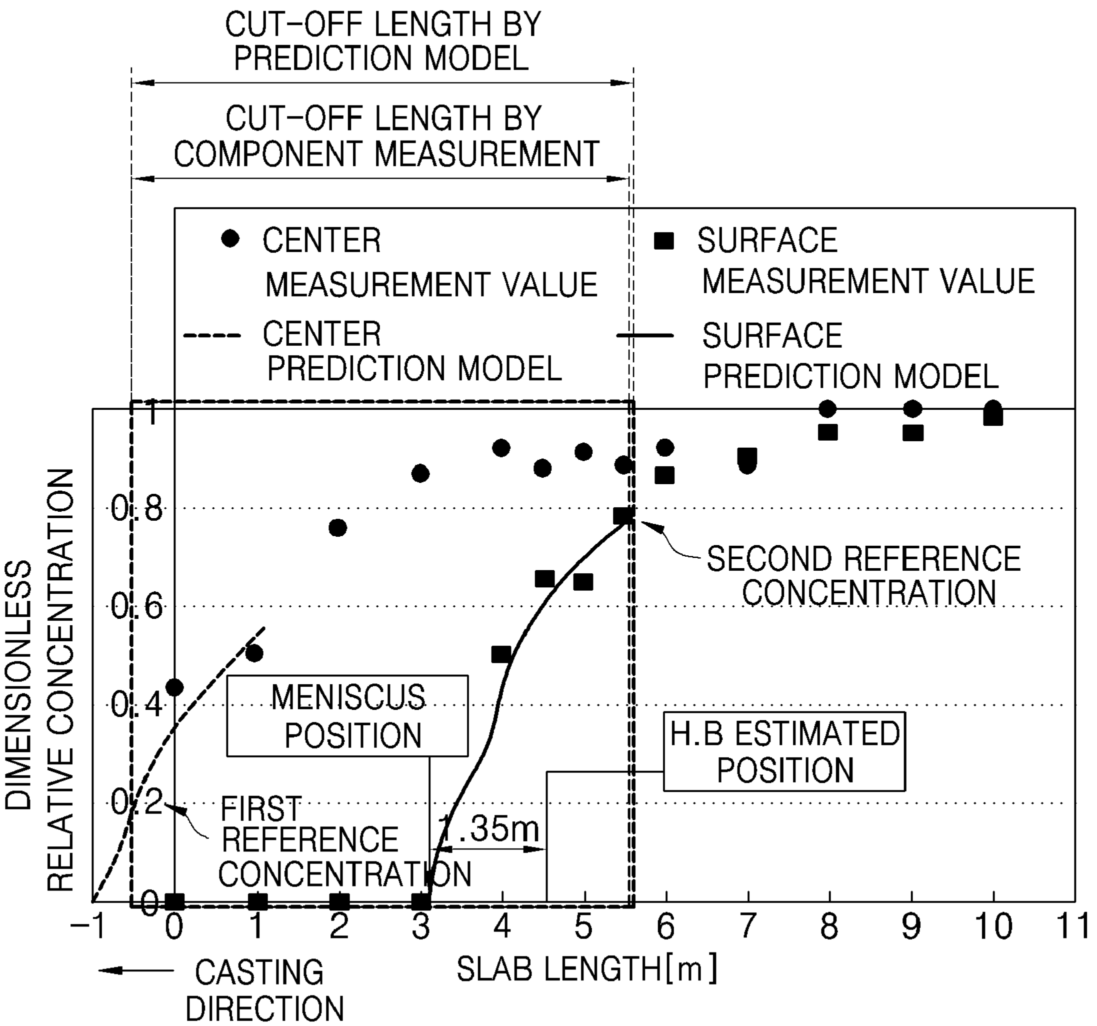
[Fig.12]


START
CALCULATE INLET VOLUMETRIC FLOW(Q_{td-in}) OF SUBSEQUENT STEEL IN TUNDISH [EQUATION 5]
S411
CALCULATE AVERAGE DIMENSIONLESS RELATIVE CONCENTRATION($C_{td-ave(t+\Delta t)}$)OF MOLTEN STEEL IN THE TUNDISH AT CURRENT TIME [EQUATION 6]
S412
CALCULATE DIMENSIONLESS RELATIVE CONCENTRATION($C_{td-out(t+\Delta t)}$)OF THE MOLTEN STEEL DISCHARGED FROM THE TUNDISH AT CURRENT TIME [EQUATION 7]
S413
CALCULATING AVERAGE DIMENSIONLESS RELATIVE CONCENTRATION ($C_{md-ave(t+\Delta t)}$)OF THE MOLTEN STEEL IN THE MOLD AT CURRENT TIME [EQUATION 8]
S414
CALCULATING DIMENSIONLESS RELATIVE CONCENTRATION($C_{md-out(t+\Delta t)}$)OF THE STRAND DISCHARGED FROM THE MOLD AT CURRENT TIME [EQUATION 9]
S415
END

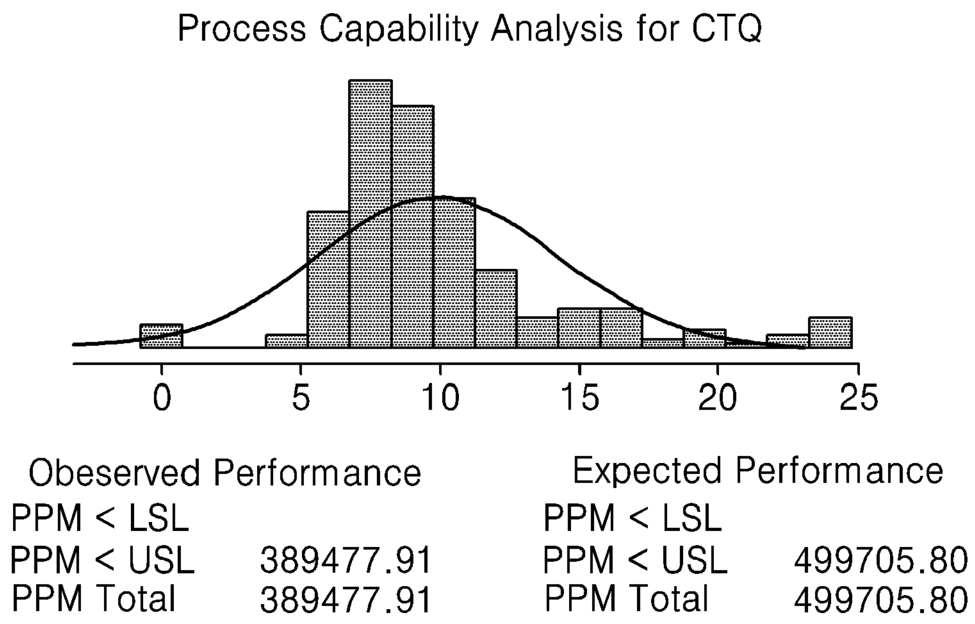
[Fig.13]


CUT-OFF LENGTH BY PREDICTION MODEL
CUT-OFF LENGTH BY COMPONENT MEASUREMENT
CENTER MEASUREMENT VALUE
SURFACE MEASUREMENT VALUE
CENTER PREDICTION MODEL
SURFACE PREDICTION MODEL
CENTER PREDICTION RESULT
SURFACE PREDICTION RESULT
DIMENSIONLESS RELATIVE CONCENTRATION
0
0.2
0.4
0.6
0.8
1
-1
0
1
2
3
4
5
6
7
8
9
10
11
CASTING DIRECTION
SLAB LENGTH[m]

[Fig.14]


CUT-OFF LENGTH BY
PREDICTION MODEL
CUT-OFF LENGTH BY
COMPONENT MEASUREMENT
CENTER
MEASUREMENT VALUE
SURFACE
MEASUREMENT VALUE
CENTER
PREDICTION MODEL
SURFACE
PREDICTION MODEL
DIMENSIONLESS
RELATIVE CONCENTRATION
1
0.8
0.6
0.4
0.2
0
SECOND REFERENCE
CONCENTRATION
MENISCUS
POSITION
H.B ESTIMATED
POSITION
FIRST
REFERENCE
CONCENTRATION
1.35m
−1
0
1
2
3
4
5
6
7
8
9
10
11
CASTING
DIRECTION
SLAB LENGTH[m]

[Fig.15]


Process Capability Analysis for CTQ
0
5
10
15
20
25
Obeserved Performance
PPM < LSL
PPM < USL 389477.91
PPM Total 389477.91
Expected Performance
PPM < LSL
PPM < USL 499705.80
PPM Total 499705.80

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- KR 100419886 **[0006]**