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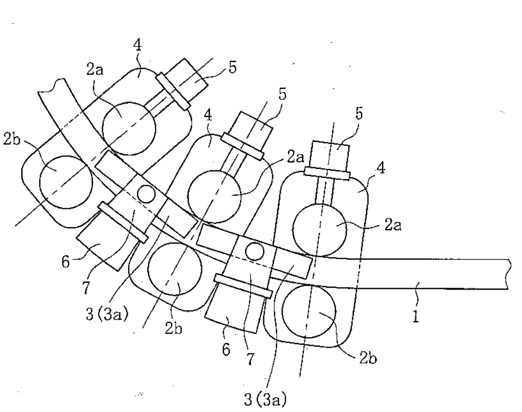
(54) HAMMERING VIBRATOR IN CONTINUOUS CASTING

(57) PROBLEM: To effectively prevent the occurrence of segregation in a casting slab, even when the slab width is large.

MEANS: Continuously performing soft reduction during continuous casting of a slab having a rectangular transverse cross section such that a solid fraction at center in a direction of thickness f_S is at least 0.1-0.9 and a reduction ratio in a direction of slab thickness is within 1% per meter of length in a direction of casting, and continuously impacting both of the opposing sides of a narrow side of the slab 1 in a direction of slab width at at least one site where the solid fraction at center in the direction of thickness f_S is within the range of 0.1-0.9, the impact being performed by using a block 3 disposed between paired pinch rolls 2a, 2b disposed adjacent to each other at a vibration frequency of impact of 4-12 Hz and an impact energy of 30-150 J.

ADVANTAGEOUS EFFECTS: The occurrence of segregation such as center segregation and V-shape segregation is effectively prevented, even in a casting slab having a large slab width, thereby resulting in a casting slab with good internal quality.

Fig.1



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Description

TECHNICAL FIELD

[0001] The present invention relates to impact-vibration equipment which impacts the narrow side of a casting slab during continuous casting, so as to prevent the occurrence of center segregation.

BACKGROUND ART

[0002] Macro-segregation in the form of center segregation or V-shape segregation readily occurs in the central region and the vicinity thereof in the direction of thickness in a continually cast slab. Macro-segregation is also referred to below as an internal defect. Center segregation is an internal defect which occurs when solute elements such as C, S, P, Mn, and the like (referred to below as segregation elements), which readily segregate, increase in concentration in the crater end of a casting slab. V-shape segregation is an internal defect which occurs when these segregation elements increase in concentration in a V-shape on the longitudinal section of a casting slab in the vicinity of the crater end of a casting slab.
[0003] When slabs in which such macro-segregation occurs are hot-processed to form products, decreased toughness and hydrogen-induced cracking tend to occur. Moreover, when these products are subjected to cold working to form final products, cracking readily occurs.
[0004] The mechanism of segregation formation in casting slabs is thought to operate in the following manner. As solidification progresses, segregation elements form between dendrite arms of columnar crystals which make up the solidification structure. Molten steel containing these enriched segregation elements flows out from between the dendrite arms of the columnar crystals as a result of solidification shrinkage of the slab or as a result of expansion of the casting slab. This is known as bulging. The enriched molten steel flows out and moves toward the point of complete solidification of the crater end of the slab, and solidifies to form an enriched zone of segregation elements. Enriched zones of segregation elements formed in this manner result in segregation.
[0005] Such segregation in casting slabs is effectively prevented by inhibiting the migration of molten steel with enriched segregation elements remaining between the dendrite arms of the columnar crystals, and by preventing the enriched molten steel from accumulating locally.
[0006] Accordingly, in Patent Reference 1 there is disclosed a method of arranging an air hammer between rolls disposed at the wide end of the slab during continuous casting, so as to impart an impact vibration of 10-100 times/min at an amplitude of about 2.0 mm or less to the slab as it moves between the rolls.

Patent Reference 1: Japanese Patent Application Kokai Publication No. S51-128631

[0007] In Patent Reference 2, the present applicant disclosed a casting method wherein vibrations are applied to a slab at a position having a rectangular cross section and containing a liquid core while the slab is being reduced by a plurality of paired guide rolls used for reduction. This method provided for continuous impact on at least one site on the surface of the casting slab within the reduction region.

Patent Reference 2: Japanese Patent Application Kokai Publication No. 2003-334641

[0008] The method recited in Patent Reference 2 causes bulging of the slab at a position containing a liquid core and reduces this bulging slab with at least one pair of reduction rolls until solidification is completed in the central region in the direction of thickness. Patent Reference 2 further discloses a method of casting such that when the foregoing occurs, impact is applied to the slab. According to this method, at least one site on the slab surface is continuously impacted within a region in the direction of casting or within the reduction region in the direction of casting, after bulging starts and before reduction starts.

DISCLOSURE OF THE INVENTION

PROBLEM TO BE SOLVED BY THE INVENTION

[0009] However, in the method disclosed in Patent Reference 1, the following serious problems occur when attempting to achieve a significant decrease in center segregation.
Bulging of the slab readily occurs between rolls arranged on the wide side of the slab. When impact vibration is applied to the wide side of the bulging slab, a large amplitude vibration cannot be applied to the central region in the direction of slab thickness. In addition, the air hammer must be disposed between the rolls, which causes undesirable interference with the spraying position for secondary cooling of the slab between the rolls. Consequently, continuous impact cannot

be applied when one aims to perform optimal secondary cooling. It is also difficult for sufficient impact energy to be propagated through the slab at an impact vibration of 10-100 times/min.

[0010] The method of Patent Reference 2 effectively prevents segregation in a slab. However, as a result of subsequent research, the inventors have determined that there are cases in which segregation is not sufficiently decreased, depending on the shape of the slab.

[0011] The reason for this is that, when impact on a slab is carried out from the narrow side of the slab, if the slab width is large, then the impact vibrations do not sufficiently propagate to the interior of the slab in the vicinity of the central region in the direction of width. In such cases, the columnar crystals are not broken up during their growth, which allows the columnar crystals to grow and makes it impossible to form a fine crystal structure. Moreover, impact is not sufficiently propagated to the equiaxed crystals formed in the vicinity of the crater end of the slab in the center region in the direction of width, thus bridging of the equiaxed crystals readily occurs.

[0012] Incidentally, under the test conditions given in paragraphs 0039-0041 of Patent Reference 2 [impact amplitude of $\pm$ 3.0 mm; impact frequency of 120 times/min (2 Hz); and block dimensions of 200 mm $\times$ 100 mm $\times$ 400 mm (62.4 kg when converted to weight)], the impact energy is 7.8 J when the impact speed is 0.5 m/sec.

[0013] The problem to be solved by the present invention is that in the case of the prior art, when impact is imparted from the narrow side of the slab during continuous casting, there are cases in which it is impossible to effectively prevent the occurrence of segregation, such as center segregation and V-shape segregation when the slab width becomes large.

MEANS FOR SOLVING THIS PROBLEM

[0014] The impact-vibration equipment for continuous casting of the present invention is equipment for effectively preventing the occurrence of slab segregation by effectively imparting impact from the narrow side of a slab containing a liquid core, even in the case of a slab having a large width. This equipment continuously performs soft reduction during continuous casting of a slab having a rectangular transverse cross section, so that the solid fraction at the center of the slab in the direction of thickness f_S is at least 0.1-0.9, and the reduction ratio in the direction of slab thickness is within 1% per meter of length in the direction of casting. The equipment continuously impacts both of the opposing sides of the narrow side of the slab in the direction of slab width in at least one site where the solid fraction at the center of the slab in the direction of thickness f_S is within the range of 0.1-0.9, at a vibration frequency of impact of 4-12 Hz and an impact energy of 30-150J.
This equipment comprises:

a block which impacts a narrow side of a casting slab;
an impact device which generates periodic impact and transmits the impact to the block; and
a position control device for setting the distance between the block and the narrow side of the slab,
wherein the block has a structure which enables it to uniformly impact at least the narrow side of the slab positioned between two sets of paired pinch rolls disposed adjacent each other in a soft reduction zone formed by paired pinch rolls in a plurality of sets of pinch rolls, and
wherein the position control device sets a gap between the front end of the block and the narrow width of the slab at a pull-back position of the block, after detecting the pushing position of the block on the narrow side of the slab, or it performs impact position control while a guide is pushed which sets the gap between the slab and the front end of the block.

[0015] The solid fraction at the center of the slab in the direction of thickness f_S can be obtained from the liquidus temperature T_L, the solidus temperature T_S, and the temperature at slab thickness center T, using the formula $f_S = (T_L - T) / (T_L - T_S)$. When the temperature at the slab thickness center T is greater than or equal to the liquidus temperature T_L of the molten steel, then $f_S = 0$, and when the temperature at the slab thickness center T is lower than the solidus temperature T_S of the molten steel, then $f_S = 1.0$. The temperature at slab thickness center T can be obtained by a simple non-steady state heat transfer calculation in the direction of slab thickness. This calculation takes into consideration the casting speed, slab surface cooling, and the physical properties of the type of steel used in casting.

ADVANTAGEOUS EFFECTS OF THE INVENTION

[0016] According to the present invention, the occurrence of segregation, such as center segregation and V-shape segregation, is effectively prevented even when casting a slab with a large slab width, thereby resulting in a cast slab with good internal quality.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017]

FIG. 1 is a schematic representation of an example of paired pinch rolls with impact devices attached as viewed from the direction of the narrow side of the slab.

FIG. 2 illustrates the relative positions of a block of an impact device and a slab, where FIG. 2 (a) illustrates a standby position of the impact device, FIG. 2 (b) illustrates a state where the block is pushed against the narrow side of a slab, and FIG. 2 (c) illustrates a state where the block has returned by a predetermined amount using the position of (b) as a starting point.

FIG. 3 illustrates the relative positions of a block of another impact device and a slab, where FIG. 3 (a) illustrates a standby position of the impact device, FIG. 3 (b) illustrates a state where a pushing guide is caused to make contact with the narrow side of a slab, and FIG. 3 (c) illustrates a state while impact force is being applied.

FIG. 4 is a graph illustrating the relationship between the length of the slab in the direction of casting and the liquid core thickness in a region where the solid fraction at the center of the slab in the direction of thickness is 0.1-0.9 for high carbon steel.

FIG. 5 is a graph illustrating the relationship between the length in the direction of casting and the liquid core thickness in a region where the solid fraction at the center of the slab in the direction of thickness is 0.1-0.9 for medium carbon steel.

FIG. 6 is a chart showing experimental results.

BRIEF DESCRIPTION OF THE REFERENCE NUMERALS

[0018]

1	Casting slab
2a, 2b	Pinch rolls
3	Block
3a	Impact plate
6	Impact device
7	Position control device
8	Pushing guide

PREFERRED EMBODIMENTS

[0019] When impacting a slab from the narrow side of the slab during continuous casting, if the slab has a large width, there are cases in which the occurrence of segregation such as center segregation and V-shape segregation cannot be effectively prevented. The present invention overcomes this problem by means of a block structure which is enabled to uniformly impact, in a continuous manner, at least the narrow side of the slab as a single unit between two sets of paired pinch rolls adjacent to each other.

EXAMPLES

[0020] Preferred embodiments for implementing the present invention are described in detail below, along with the process leading to the formation of the invention.

[0021] As mentioned above, when impact on a slab is carried out from the narrow side of the slab, if the slab width is large, then the impact vibrations do not sufficiently propagate to the interior of the slab in the vicinity of the central region, as viewed in the widthwise direction. In such cases, the columnar crystals are not broken up during their growth. This allows the columnar crystals grow, and makes it impossible to form a fine crystal structure and prevents a sufficient segregation decreasing effect from being achieved. Moreover, the impact does not sufficiently reach the equiaxed crystals formed in the vicinity of the crater end of the slab in the center region in the widthwise direction. Thus, bridging of the equiaxed crystals readily occurs and a sufficient segregation decreasing effect is not achieved.

[0022] Accordingly, the inventors conducted repeated experiments in applying impact from both of the opposing sides of the narrow side of the slab containing a liquid core, so as to prevent the occurrence of center segregation or V-shape segregation. Using these experiments, the inventors investigated how to apply impact from the narrow side of the slab so that impact vibrations would sufficiently propagate to the interior of the slab in the vicinity of the central region in the direction of slab width.

[0023] As a result, the inventors have discovered that there exist impact frequencies and impact energies that produce an impact-vibration effect when the solid fraction at the center of the slab in the direction of thickness f_S in a range of 0.1-0.9. Additionally, the inventors have discovered that applying impact within almost this entire range is very effective in decreasing segregation.

[0024] The inventors have also disclosed a method for continuous casting of steel in which soft reduction is carried out when casting slabs having a rectangular transverse cross section, with the solid fraction at the center of the slab in the direction of thickness f_S within a range of 0.1-0.9 (Japanese Patent Application No. 2006-53057). When performing soft reduction, this method applies a continuous impact in the direction of slab width at least at one site where the solid fraction f_S is within this range.

[0025] When this method is implemented, soft reduction is continuously carried out with a reduction ratio in the direction of slab thickness of less than 1% per meter in the direction of casting length. Moreover, both of the opposing sides of the narrow side of the slab are continuously impacted in the direction of slab width at a vibration frequency of impact of 4-12 Hz and at an impact energy of 30-150 J.

[0026] In Japanese Patent Application No. 2006-53057 equipment for implementing the foregoing method is disclosed. This equipment is impact-vibration equipment having a structure that enables it to uniformly impact as a single unit the entire surface of the narrow side of the slab at both of the opposing sides of the narrow side of the slab, respectively, in at least one segment among segments formed by a plurality of guide rolls.

[0027] Depending on the features of the continuous casting machine, there are cases when soft reduction in the continuous casting of steel is not performed in segments formed by a plurality of guide rolls, but rather, by a pinch roll assembly.

When the inventors conducted impact tests on a pinch roll assembly in the method of continuous casting of steel disclosed in Japanese Patent Application No. 2006-53057, they were able to obtain satisfactory effects similar to when impact was applied to the segments described above.

[0028] When impact is applied to such a pinch roll assembly, the structure is simpler than when impact is applied to segments, as shown in Table 1 below. This structure also provides advantages in that it is easy to secure set-up space and it is easy to maintain the equipment.

[0029]

TABLE 1

	Pinch Roll Reduction	Segment Reduction
Mechanism	Single roll reduction	Multiple roll uniform reduction
Structure	No need to consider rigidity of reduction frame (simple)	Must consider rigidity of reduction frame (complex)
Control	Control includes bending and straightening counter-forces	Control of reduction counter-forces
Impact imparting position	Latter half of machine length	Middle to latter half of machine length
Set-up space	Easy to secure space (easy to maintain)	Difficult to secure space (difficult to maintain)

[0030] The impact-vibration equipment for continuous casting of the present invention is based on the above findings. This equipment continuously performs soft reduction during continuous casting of a slab having a rectangular transverse cross section, so that the solid fraction at the center of the slab in the direction of thickness f_S is at least 0.1-0.9 and the reduction ratio in the direction of slab thickness is within 1% per meter of length in the direction of casting. The equipment continuously impacts both of the opposing sides of the narrow side of the slab in the direction of slab width in at least one site where the solid fraction at the center of the slab in the direction of thickness f_S is within a range of 0.1-0.9 at a vibration frequency of impact of 4-12 Hz and an impact energy of 30-150 J.

This equipment comprises:

a block which impacts a narrow side of a casting slab;
an impact device which generates periodic impact and transmits the impact to the block; and

a position control device for setting the distance between the block and the narrow side of the slab,
wherein the block has a structure which enables it to uniformly impact, as a single unit, the narrow side of the slab positioned between at least two sets of paired pinch rolls disposed adjacent to each other in a soft reduction zone formed by paired pinch rolls in a plurality of sets of pinch rolls, and
wherein the position control device sets a gap between a front end of the block and the narrow width of the slab at a pull-back position of the block, after detecting the pushing position of the block on the narrow side of the slab, or it performs position control while a guide is pushed which sets the gap between the slab and the front end of the block.

[0031] The impact-vibration equipment for continuous casting of a slab of the present invention includes a casting slab 1, which is solidified and cast in a mold and is disposed on the downstream side in the direction of casting, and a block 3 is disposed between a plurality of sets of paired pinch rolls 2a, 2b, as shown in FIG. 1.

[0032] In FIG. 1, Reference Numeral 3 represents a block which impacts the narrow side of the casting slab 1. This block 3 has a structure possessing an impact plate 3a disposed between at least two adjacent sets of paired pinch rolls 2a, 2b in the plurality of sets of paired pinch rolls 2a, 2b. This structure makes it possible to uniformly and continuously impact at least the narrow side of the slab 1 as a single unit at a position between two sets of paired pinch rolls 2a, 2b disposed adjacent to each other. From the standpoint of durability and heat resistance, it is desirable that this block 3 be cast.

[0033] Bridging of equiaxed crystals or the like occurs at positions where the solid fraction at the center in the direction of thickness of casting slab 1 is 0.1 or higher. However, bridging can re-occur if the impact does not completely stop the bridging. Therefore, it is desirable to thoroughly implement continuous impact in a range where the solid fraction at the center in the direction of thickness of casting slab 1 is 0.4 or higher, and it is desirable to impact the entire length between the plurality of sets of paired pinch rolls 2a, 2b.

[0034] Moreover, the solid fraction ranging between 0.1 and 0.9 at the center in the direction of thickness of the casting slab is within a relatively broad range, and the position described above constantly changes during the actual casting operation, as described below. Therefore, there are cases where the impact between two adjacent sets of paired pinch rolls 2a, 2b is sufficient. There are also cases where impact is needed between three adjacent sets of paired pinch rolls 2a, 2b, as shown in FIG. 1. However, installation costs would be excessive if the equipment was required to operate over the entire range of the solid fraction at the center in the direction of thickness of casting slab and to impact over a lengthy area. Accordingly, impact is implemented between three adjacent sets of paired pinch rolls 2a, 2b, for example, which is considered to be a range that will achieve the impact-vibration effect.

[0035] In other words, it is crucial to impart vibration over a broad range of locations in the direction of casting of the casting slab 1, and, if possible, it is desirable that the length of the block 3 in the direction of casting be a length that enables impact over the entire region of the plurality of sets of paired pinch rolls 2a, 2b. However, in practice, the paired pinch rolls 2a, 2b are installed in and removed from the continuous casting machine, thus they should be as long as possible to enable impact without interfering with the various elements of the continuous casting machine.

[0036] The paired pinch rolls 2a, 2b have a structure that makes it possible to adjust the amount of reduction and also to eliminate soft reduction through the use of a hydraulic cylinder 5, which is typically attached to an upper frame 4.

[0037] Reference Numeral 6 represents an impact device to which the block 3 is attached at the front end. The impact device 6 generates periodic impact and transmits this impact to the block 3. An air cylinder, for example, may be used for this purpose. This impact device 6 is disposed, for example, in two places on both of the opposing sides of the narrow side of the slab 1 that contains a liquid core.

[0038] Reference Numeral 7 represents a position control device, which pushes the block 3 from the standby position shown in FIG. 2 (a), to the narrow side of the slab 1 [*see* FIG. 2 (b)]. After detecting the pushing position, the position control device sets the gap L (impact amplitude: about 8 mm) between the front end surface of the block 3 and the narrow side of the slab 1, at the pull-back position of the block 3 [*see* FIG. 2 (c)].

[0039] The position control device 7 is not limited to the structure shown in FIG. 2, and may also have the structure shown in FIG. 3. The position control device 7 of FIG. 3 sets the gap L (impact amplitude: about 8 mm) between the front end surface of the block 3 and the narrow side of the slab 1 by causing a pushing guide 8 to move from the standby position shown in FIG. 3 (a) to a position where it makes contact with the narrow side of the slab 1 [*see* FIG. 3 (b)]. While impact is being performed as shown in FIG. 3 (c), this position control device 7 creates a state in which the pushing guide 8 is pushed against the narrow side of the slab 1. The conditions for installing the pushing guide 8 are set in advance, so that the gap L between the block 3 and the casting slab 1 has a predetermined length.

[0040] Actually, it is necessary to use the narrow side of the slab 1 during casting as a standard while performing the position setting, since the gap L between the block 3 and the narrow side of the casting slab 1 depends on the width of the slab 1 that is being cast. This gap L affects the stroke of the impact device 6. If the stroke is insufficient, then the impact speed cannot be ensured during impact and sufficient impact energy cannot be produced. Therefore, when impact begins, the relative positions of the block 3 and the narrow side of the slab 1 are adjusted in what is called positioning.

[0041] Using the impact-vibration equipment of the present invention, when continuously casting the slab 1 having a rectangular transverse cross section, soft reduction is continuously carried out so that the solid fraction at the center in the direction of thickness f_S is at least 0.1-0.9, and the reduction ratio in the direction of slab thickness is within 1% per meter of length in the direction of casting, and the equipment continuously impacts both of the opposing sides of the narrow side of the slab 1 in the direction of slab width at least one site where the solid fraction at the center in the direction of thickness f_S is within a range of 0.1-0.9 with a vibration frequency of impact of 4-12 Hz and an impact energy of 30-150 J.

[0042] The following is an explanation of the reason why the present invention continuously impacts both of the opposing sides of the narrow side of the slab 1 in the direction of slab width at at least one site where the solid fraction at the center in the direction of thickness f_S is within a range of 0.1-0.9.

[0043] The reason is that since bridging of equiaxed crystals or the like occurs at positions on the casting slab 1 where the solid fraction at the center in the direction of thickness of the casting slab 1 is 0.1 or higher, equiaxed crystals do not sufficiently form at positions where the solid fraction at the center in the direction of thickness of casting slab is less than 0.1, and the impact effect on the casting slab 1 is small. Another reason is that if the solid fraction at the center in the direction of thickness of the casting slab 1 exceeds 0.9, then the liquid molten steel no longer readily vibrates and flows, thus bridging of equiaxed crystals or voids formed by bridging become difficult to break by impacting the casting slab 1.

[0044] FIG. 4 is a graph illustrating length in the direction of casting and the liquid core thickness in a region where the solid fraction at the center in the direction of thickness is 0.1-0.9 in the case of high carbon steel with a thickness of 300 mm (C = 0.40 mass %) when continuous casting is performed under casting conditions where the casting speed is 0.75 m/min, and the specific cooling intensity in the secondary cooling is 0.8 L/kg.

[0045] As shown in FIG. 4, the solid fraction at the center in the direction of thickness f_S in the range of 0.1-0.9 referred to in this invention forms a long region in the direction of casting. The double-headed arrows shown in two places in FIG. 4 illustrate examples of impact plates for imparting impact to the slab being arranged in the respective positions with the distance being taken from the mold output side.

[0046] The example of the impact plate of FIG. 4 illustrates continuous impact on both of the opposing sides of the narrow side of the slab 1 in the direction of slab width, when the solid fraction at the center in the direction of thickness f_S is in the range 0.4-0.8.

[0047] FIG. 5 is a graph illustrating length of the slab 1 measured in the direction of casting and the liquid core thickness in a region where the solid fraction at the center in the direction of thickness f_S is 0.1-0.9 in the case of medium carbon steel with a thickness of 250 mm (C = 0.06 mass %) when continuous casting is performed under conditions where the casting speed is 1.0 m/min, and the specific cooling intensity in the secondary cooling is 0.8 L/kg.

[0048] The double-headed arrows shown in the two places in FIG. 5 illustrate examples of impact plates for imparting impact to the slab being arranged in a position at the distance of these two places from the mold output side. The example of the impact plate of FIG. 5 illustrates continuous impact on both of the opposing sides of the narrow side of the slab 1 in the direction of slab width when the solid fraction at center in the direction of thickness f_S is in the range 0.25-1.0, which range also includes the range 0.25-0.9.

[0049] In the present invention, soft reduction is continuously carried out on the casting slab, so that the solid fraction at the center in the direction of thickness f_S is in the range 0.1-0.9 and so that the reduction ratio in the direction of slab thickness is within 1% per meter of length in the direction of casting. The reason for this is that when the inventors took into consideration the amount of solidification shrinking and the amount of heat shrinking in computing the roll gap (the amount of roll gap squeezing in the direction of casting) of the paired pinch rolls 2a, 2b, the effective range for decreasing center segregation is such that the reduction ratio in the direction of slab thickness is within about 1% per meter of length in the direction of casting.

[0050] That is to say, if reduction is carried out with the reduction ratio in the direction of slab thickness greatly exceeding 1% per meter of length in the direction of casting and at a low solid fraction range, then strain at the solid-liquid interface greatly increases and internal cracking readily occurs. When soft reduction is carried out continuously, internal cracking starts to be suppressed, however if reduction is carried out at least at a level in which the amount of solidification shrinkage is offset it is sufficient. In this case, the reduction ratio in the direction of thickness of the slab 1 is within 1% per meter of length in the direction of casting.

[0051] Moreover, in the present invention, the narrow side of the slab is subjected to continuous impact, rather than the wide side of the slab. The slab readily undergoes bulging between the rolls on the wide side, and if impact vibration is applied to a bulging wide side, then fluctuation in the surface level of molten steel in the mold is encouraged on the upstream side. Furthermore, it is impossible to apply a large amplitude vibration to the slab thickness center, since the slab 1 is bulging. Additionally, provision of the impact imparting means causes the drawback of interference with the spraying position for secondary cooling of the slab between the rolls, thus making it impossible to continuously apply impact.

[0052] By contrast, if impact vibration is applied to the narrow side of the slab, a large change in volume will not occur in comparison to the wide side, even if dislocation occurs due to the impact. Thus, the above described problems do not arise, as do in the case when impact vibration is applied to the wide side. Moreover, few installation problems occur when setting up the impact imparting means.

[0053] For example, if the slab width is set at 2,300 mm and the width of the block 3 is set at 200 mm, and if the impact vibration is to be applied to the wide side if the slab, then the site where impact vibration can be applied is 200 mm in the direction of casting. By contrast, if the impact vibration is to be applied to the narrow side of the slab, the site where the impact vibration can be applied is on the order of 2,300 mm in the direction of casting, for example, as long as the length of the impact plate is sufficiently maintained. Therefore, if impact vibration is applied to the narrow side of the slab, then the volume change is on the order of 1/11.5.

[0054] Moreover, in the present invention, the reason why the vibration frequency of impact is set at 4-12 Hz during impact is that if the vibration frequency of impact is less than 4 Hz, then the impact energy is not sufficiently transmitted to the liquid core of the slab, so there is little center segregation decreasing effect.

[0055] Higher frequencies are desirable from the standpoint of imparting impact energy, but if an air cylinder system is used as a means for imparting impact energy, then turbulence develops in the vibration waveform as the impact frequency increases. Moreover, when the slab 1 undergoes impact, sufficient effects are achieved if impact is applied up to 12 Hz, depending on the deformation characteristics of the slab 1. In addition, if the operator intends to increase the impact frequency, the air supply pressure must be raised, which presents concerns regarding the effect of air supply pressure on peripheral equipment due to the impact. Thus, the upper limit of the range within which center segregation can be decreased is set at 12 Hz.

[0056] In the present invention, the impact energy is set at 30 J -150 J. This is because if impact energy exceeding 150 J is applied, then peripheral equipment installed in the continuous casting machine can be damaged. If impact energy is applied above the necessary level, then the durability of the impact device 6 itself can be compromised.

[0057] On the other hand, if the impact energy is less than 30 J, then the impact vibration is not sufficiently propagated from the narrow side of the slab 1 to the slab interior in the vicinity of the center in the direction of slab width.

[0058] The impact energy E (J) can be obtained from the equation $E = 0.5 \times M \times V^2$, where M (kg) is the weight of the block 3, and V (m/sec) is the impact speed of the block 3 moving toward the slab 1. Therefore, the impact energy can be changed either by changing the weight of the block 3, or by changing the impact speed of the block 3 moving toward the slab 1. However, the impact frequency is of particular importance since bridging cannot be completely suppressed, particularly when there is a high solid fraction at the final stage of solidification, even if a high impact energy is applied several times every minute.

[0059] The range of vibration frequency of impact established for the present invention does not change with blooms or slabs of different slab widths. However, the optimal impact energy changes, since the volumes of liquid held by blooms and slabs can differ.

[0060] When soft reduction is performed during continuous casting using the impact-vibration equipment of the present invention, in a range from the upstream side to the downstream side at a position where the surface of the slab 1 is impacted, it is desirable for the reduction ratio to be 0.5-2.5 mm per meter of length in the direction of casting, where the solid fraction at center in the direction of thickness f_S of the slab 1 is 0.1-0.9.

[0061] Accordingly, in the present invention, when subjecting the slab 1 to soft reduction, vibrations due to impact can be sufficiently propagated to the interior of the slab 1, by applying to the slab 1 impact vibration which satisfies the optimal impact conditions, thereby making it possible to achieve an even greater segregation decreasing effect.

WORKING EXAMPLES

[0062] Following is an explanation of the results of experiments performed to test the present invention.
An impact device such as that shown in FIG. 1 was installed in two pairs of pinch rolls in the direction of casting. High carbon steel with a composition shown in Table 2 below was cast into blooms or slabs. The size was 250-310 mm thick and 425 mm or 2,300 mm wide. The casting speed was set at 0.70 m/min or 0.75 m/min.

[0063]

TABLE 2

	[C]	[Si]	[Mn]	[P]	[S]	Residue
High carbon steel	0.26-1.00	0.02-2.00	0.10-3.00	0.08 or less	0.02 or less	Fe and impurities
(Unit: Mass %)						

[0064] With the solid fraction at the center in the direction of thickness set at 0.1-0.9 during soft reduction, slabs were subjected to soft reduction at a ratio of 1.0 mm per meter of length in the direction of casting. Uniform conditions were set such that the specific cooling intensity was 0.8 L/kg in secondary cooling.

[0065] Using an air cylinder type impact device, two sites on both sides of the narrow side of a slab at a position containing a liquid core were continuously impacted at a frequency of 4 Hz or 6 Hz (240 times/min or 360 times/min) so that the amplitude of vibrations at the impact surface was ± 3 mm.

[0066] The impact conditions were set such that the block weight was 450 kg and the impact speed was about 0.47 m/sec or 0.71 m/sec (the impact energy was 50 J or 114 J). The shape of the surface of the block attached to the front end of the impact device that comes into contact with the bloom or the slab had a width in the direction of slab thickness of about 200 mm, and a length in the direction of casting of about 1,100 mm.

[0067] In casting tests, slab samples were removed, and test pieces were taken from these samples at positions corresponding to the thickness of a transverse cross section and corresponding to the center in the direction of width, on the order of 10 mm in the direction of thickness, including the center in the direction of thickness, 200 mm in the direction of width, and 15 mm in the direction of casting.

[0068] Using these test pieces, the carbon concentration was analyzed by removing chips from 26 sites at positions corresponding to the center in the direction of slab thickness, with a drill blade 2 mm in diameter at a pitch of 7 mm. The resulting carbon concentration (mass %) was divided by the carbon concentration of molten steel in the ladle, resulting in the ratio C/C0, and the maximum values for this ratio (maximum center segregation ratio) were obtained.

[0069] The test conditions are given in Table 3 below. This test was performed on: an inventive example (high carbon steel C) to which impact vibration was applied between pinch rolls using the impact-vibration equipment of the present invention; a comparative example (high carbon steel B) to which impact vibration was applied at a segment, using impact-vibration equipment disclosed in Japanese Patent Application No. 2006-53057; and a comparative example (high carbon steel A) produced without applying impact vibration.

[0070]

TABLE 3

Test Piece	Impact Vibration	Casting Speed	Impact Vibration Conditions			Slab Dimensions
			Solid Fraction	Vibration Frequency of Impact	Impact Energy	
Comparative Example (High carbon steel A)	None	0.7 m/min	0.1-0.9	-	-	310 × 425 mm
Comparative Example (High carbon steel B)	Impact vibration at segment	0.7 m/min	0.4-0.9	4 Hz	50 J	310 × 425 mm
Inventive Example (High carbon steel C)	Impact vibration between pinch rolls	0.75 m/min	0.4-0.8	6 Hz	114 J	300 × 2,300 mm

[0071] The test results are shown in FIG. 6. In tests where impact vibration was applied, no significant differences were found in the size of the maximum center segregation in any of the samples, and the maximum center segregation ratio was a favorable 1.15 or less in all cases. On the other hand, in tests where impact vibration was not applied, there were cases in which the maximum center segregation ratio exceeded 1.15, as the slab width increased. In evaluating test results, a maximum center segregation ratio of 1.15 or less was considered good, and results exceeding that value were considered poor.

[0072] The present invention is not limited to the foregoing examples, and the embodiments can of course be suitably modified, as long as they are within the scope of the technical ideas recited in the claims.

[0073] For example, in the above description, an air cylinder was used as the impact device 6. However, any method may be used, as long as it is able to drive the block 3. Examples include a hydraulic cylinder, a method using a leaned cam, or a method using a spring.

INDUSTRIAL APPLICABILITY

[0074] The present invention can be applied not only to high carbon steel slabs as described in the examples, but also to continuous casting of other types of steel, such as medium carbon steel slabs and low carbon steel slabs.

Claims

1. Impact-vibration equipment for continuous casting of a metal, which continuously performs soft reduction during continuous casting of a slab having a rectangular transverse cross section so that the solid fraction at a center in the direction of thickness f_S is at least 0.1-0.9, and the reduction ratio in the direction of the slab thickness is within 1% per meter of length in the direction of casting, the impact-vibration equipment continuously impacting both of the opposing sides of a narrow side of the slab in a direction of slab width in at least one site where a solid fraction at the center of the slab in the direction of thickness f_S is within a range of 0.1-0.9 at a vibration frequency of impact of 4-12 Hz, and an impact energy of 30-150 J, the equipment comprising:

   a block that impacts a narrow side of a casting slab;
   an impact device that generates periodic impact and transmits the impact to the block; and
   a position control device for setting the distance between the block and the narrow side of the casting slab,
   wherein the block has a structure that enables it to uniformly impact at least the narrow side of the slab as a single unit between two sets of paired pinch rolls disposed adjacent to each other in a soft reduction zone formed by a set of paired pinch rolls in a plurality of sets of paired pinch rolls, and
   wherein the position control device sets a gap between a front end of the block and the narrow width of the slab at a pull-back position of the block, after detecting a pushing position of the block on the narrow side of the slab, or it performs position control while a guide is pushed which sets the gap between the slab and the front end of the block.

Fig.1

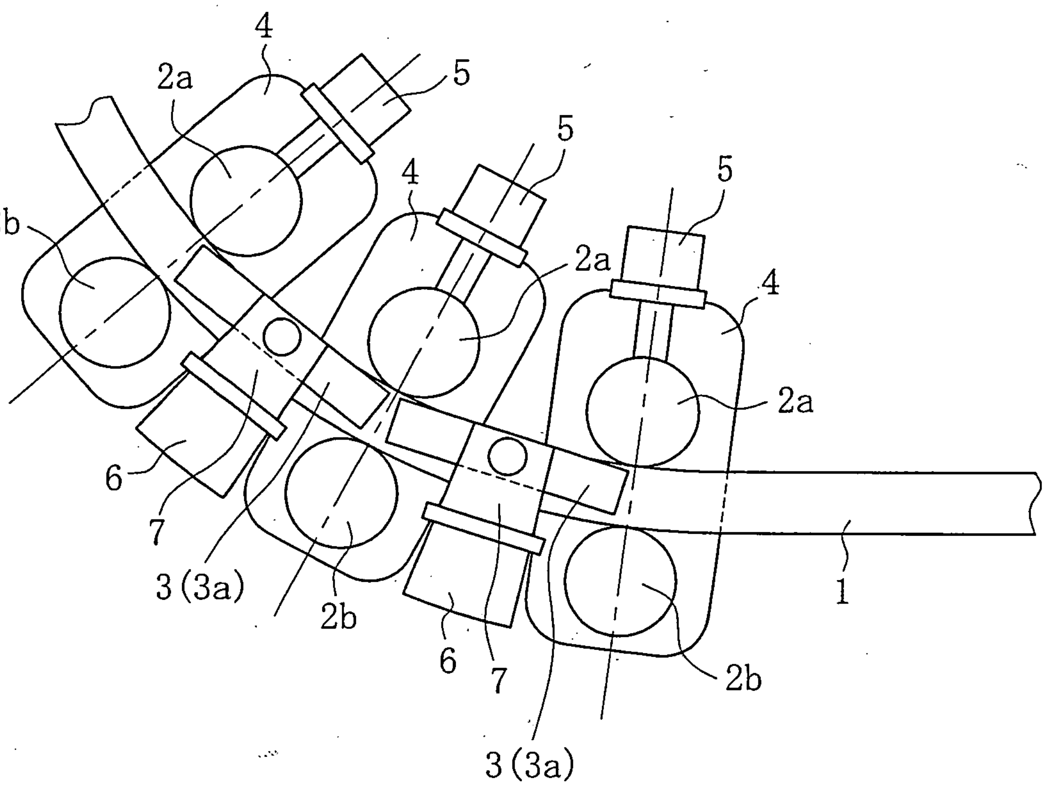


Fig.2

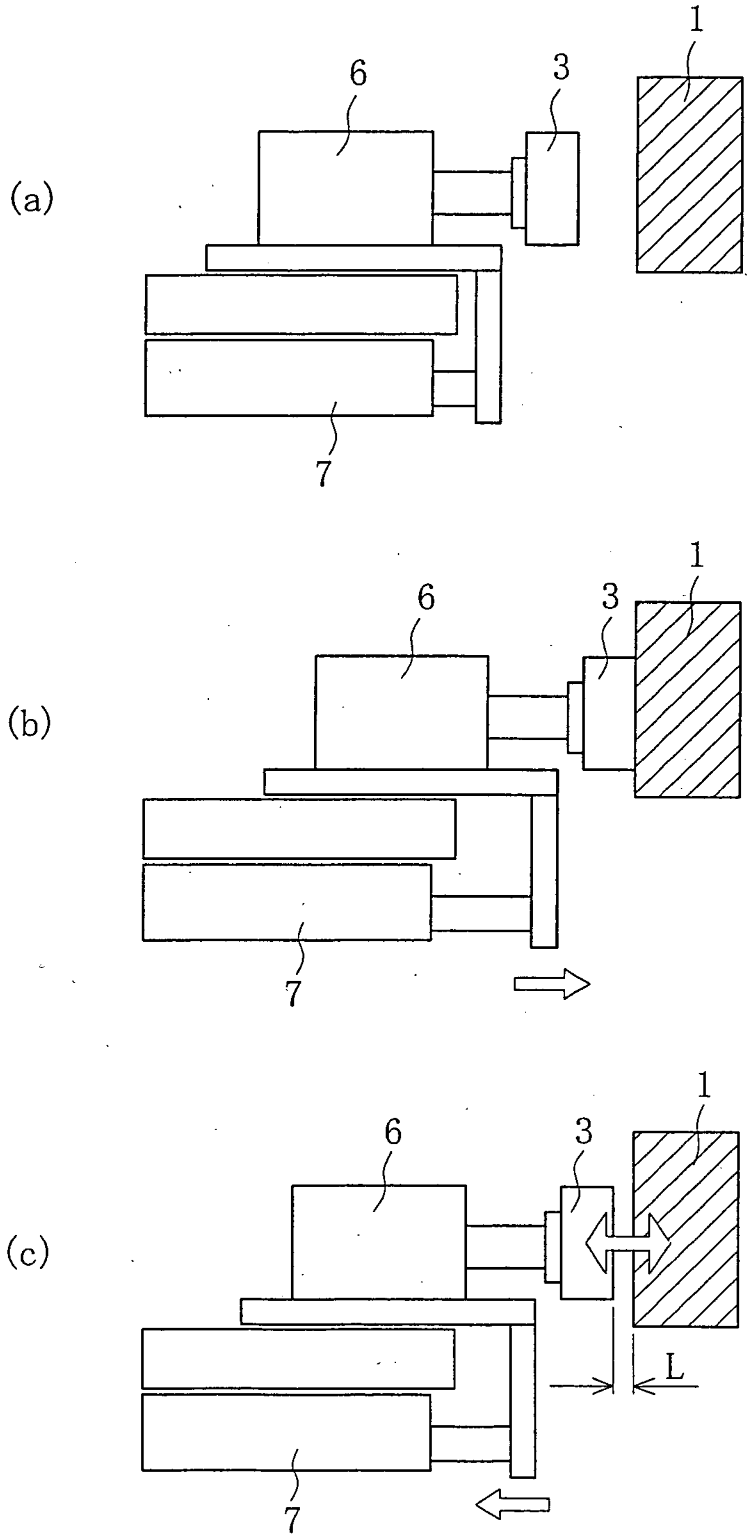


Fig.3

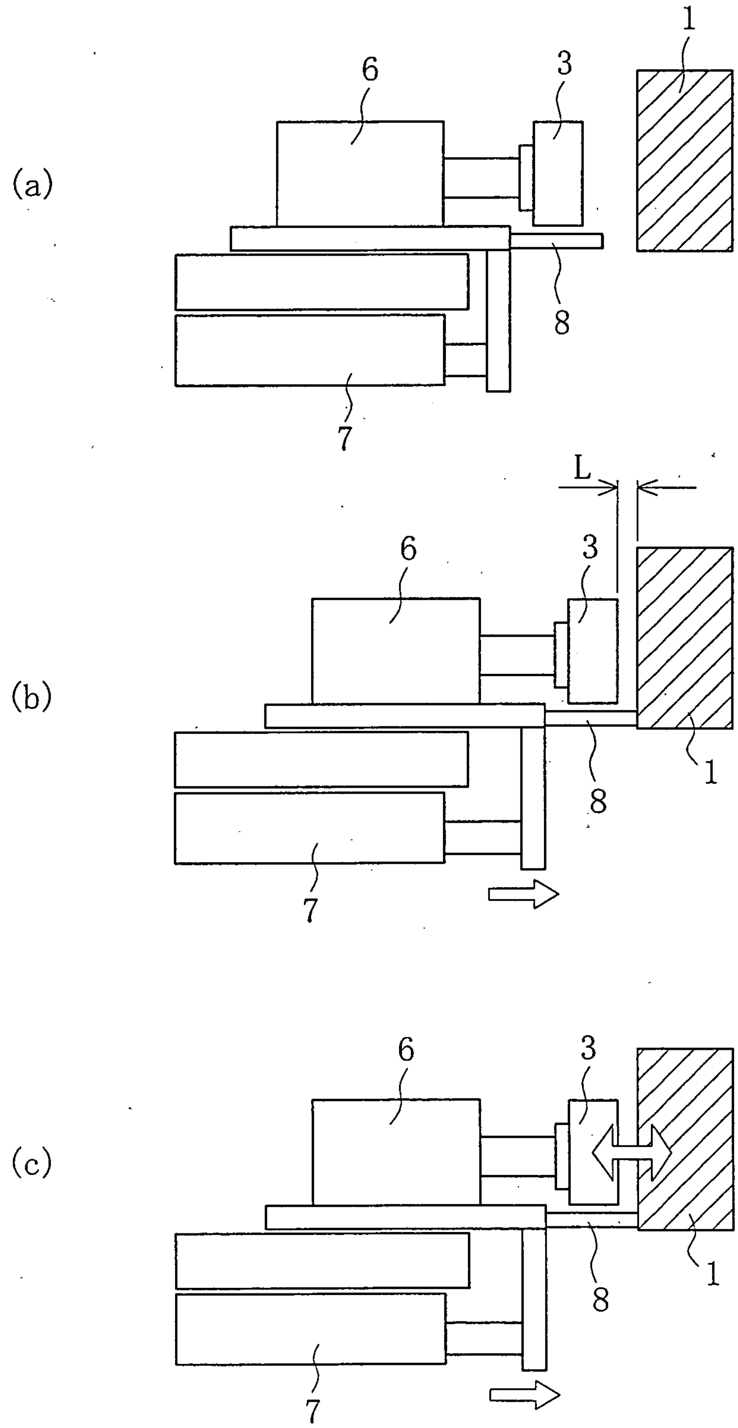


Fig.4

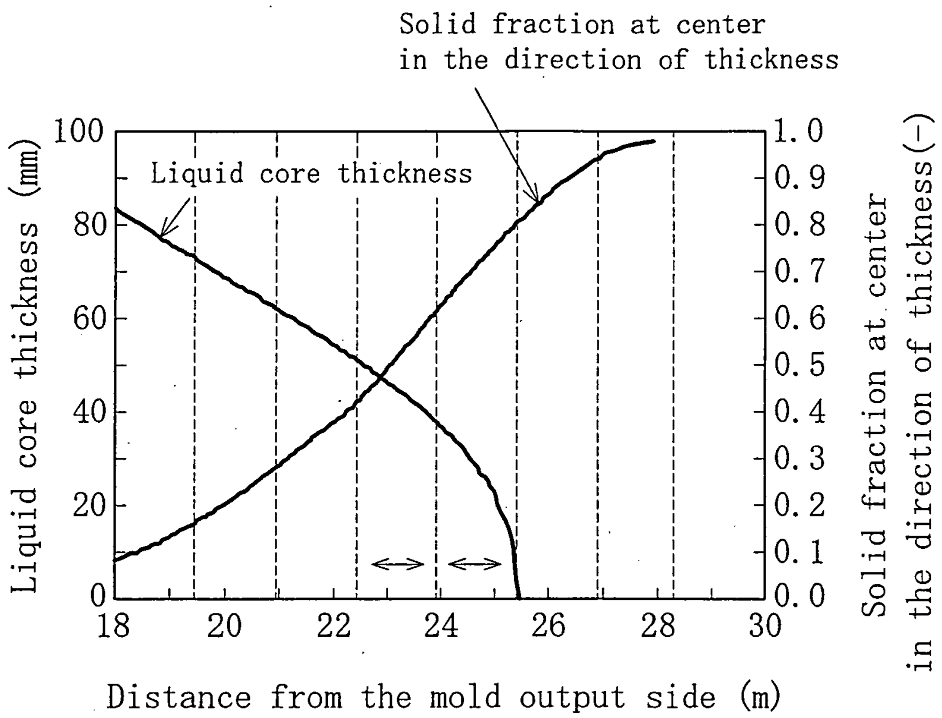

Solid fraction at center
in the direction of thickness
Liquid core thickness
Liquid core thickness (mm)
100
80
60
40
20
0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
18
20
22
24
26
28
30
Distance from the mold output side (m)
Solid fraction at center
in the direction of thickness(-)

Fig.5

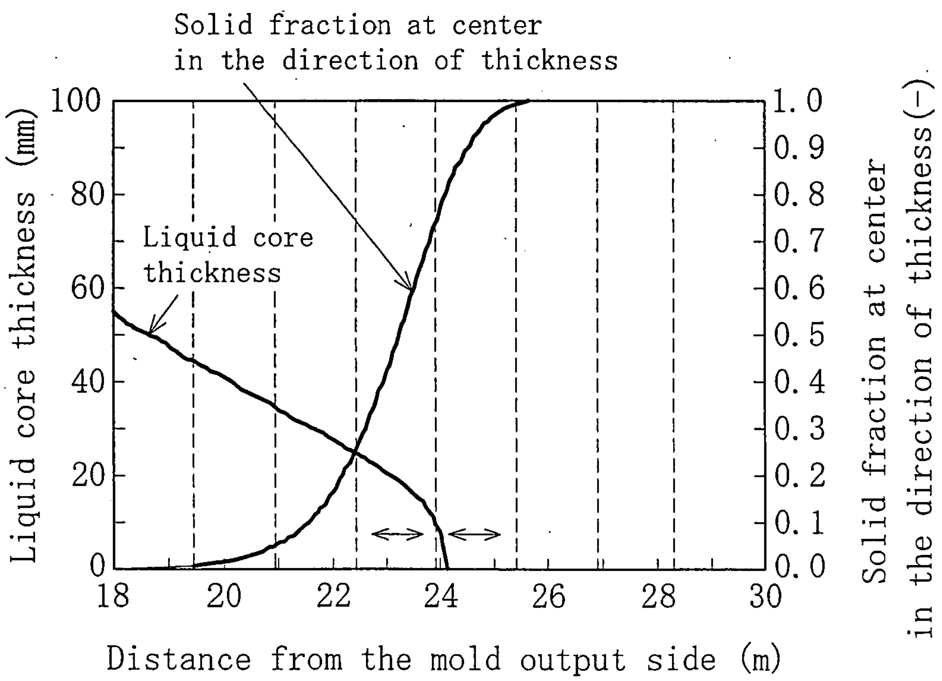
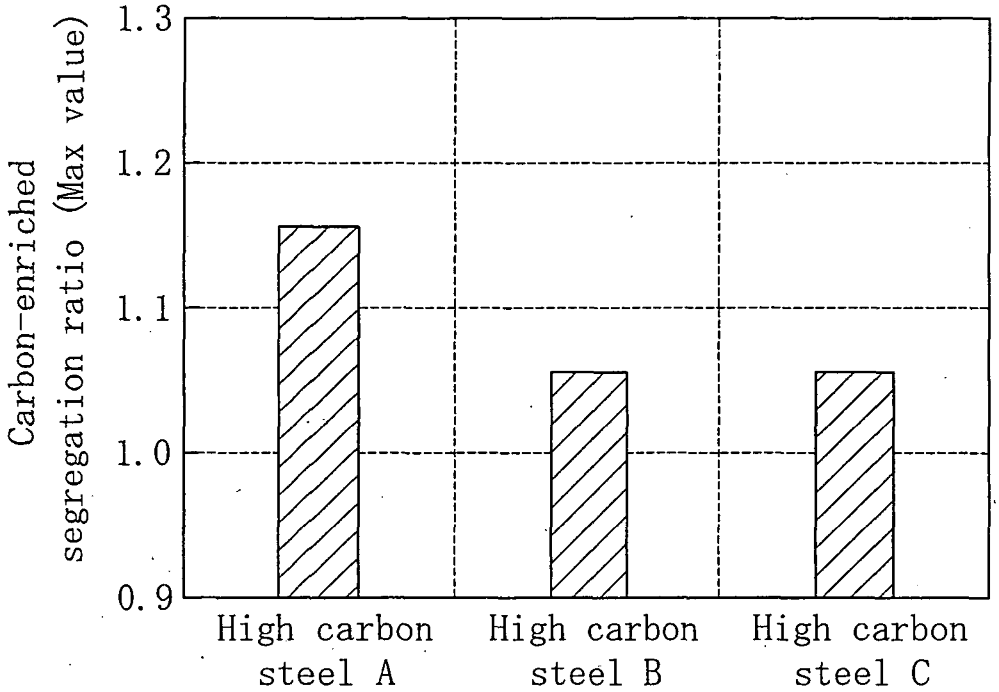

Solid fraction at center
in the direction of thickness
Liquid core
thickness
Liquid core thickness (mm)
100
80
60
40
20
0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
18
20
22
24
26
28
30
Distance from the mold output side (m)
Solid fraction at center
in the direction of thickness(-)

Fig.6


Carbon-enriched
segregation ratio (Max value)
1.3
1.2
1.1
1.0
0.9
High carbon
steel A
High carbon
steel B
High carbon
steel C

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2008/063049

A. CLASSIFICATION OF SUBJECT MATTER
B22D11/128(2006.01)i, *B22D11/12*(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B21J13/00, B22D11/128, B22D11/12

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2008
Kokai Jitsuyo Shinan Koho	1971-2008	Toroku Jitsuyo Shinan Koho	1994-2008

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2002-273554 A (Sumitomo Metal Industries, Ltd.), 25 September, 2002 (25.09.02), Claims; Par. Nos. [0028] to [0034]; Figs. 1 to 2 (Family: none)	1
Y	JP 2006-110620 A (Sumitomo Metal Industries, Ltd.), 27 April, 2006 (27.04.06), Par. Nos. [0039] to [0044] (Family: none)	1

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 September, 2008 (11.09.08)	22 September, 2008 (22.09.08)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (April 2007)

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2008/063049

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 120076/1984(Laid-open No. 36335/1986) (Aida Engineering, Ltd.), 06 March, 1986 (06.03.86), Column 8, line 4 to column 10, line 4; Fig. 1 (Family: none)	1

Form PCT/ISA/210 (continuation of second sheet) (April 2007)

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP S51128631 B **[0006]**
- JP 2003334641 A **[0007]**
- JP 2006053057 A **[0024] [0026] [0027] [0069]**