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(54) **CONTINUOUS STEEL CASTING METHOD**

(57) Surface cracking caused by nonuniform cooling of a solidifying shell at the initial stage of solidification is prevented, and the occurrence of center segregation in a thicknesswise central portion of a strand is reduced.

Metal-filled portions with different thermal conductivity filled with a metal having a thermal conductivity that differs by at least 20% from the thermal conductivity of a mold copper plate of a continuous casting mold are disposed on an inner wall surface of the mold copper plate in a region extending from a position at least 20 mm above the position of a meniscus to a position at least 50 mm and at most 200 mm below the position of the meniscus. The area fraction of the total area of the metal-filled portions with different thermal conductivity relative to the area of the inner wall surface on which the plurality of metal-filled portions with different thermal conductivity are disposed is from 10% to 80% inclusive. A distance (D1) and an oscillation mark pitch (OMP) that is derived from the frequency of oscillation (f) and a casting speed (Vc) satisfy formula (1) below, and a distance (D2) satisfies formula (2) below.

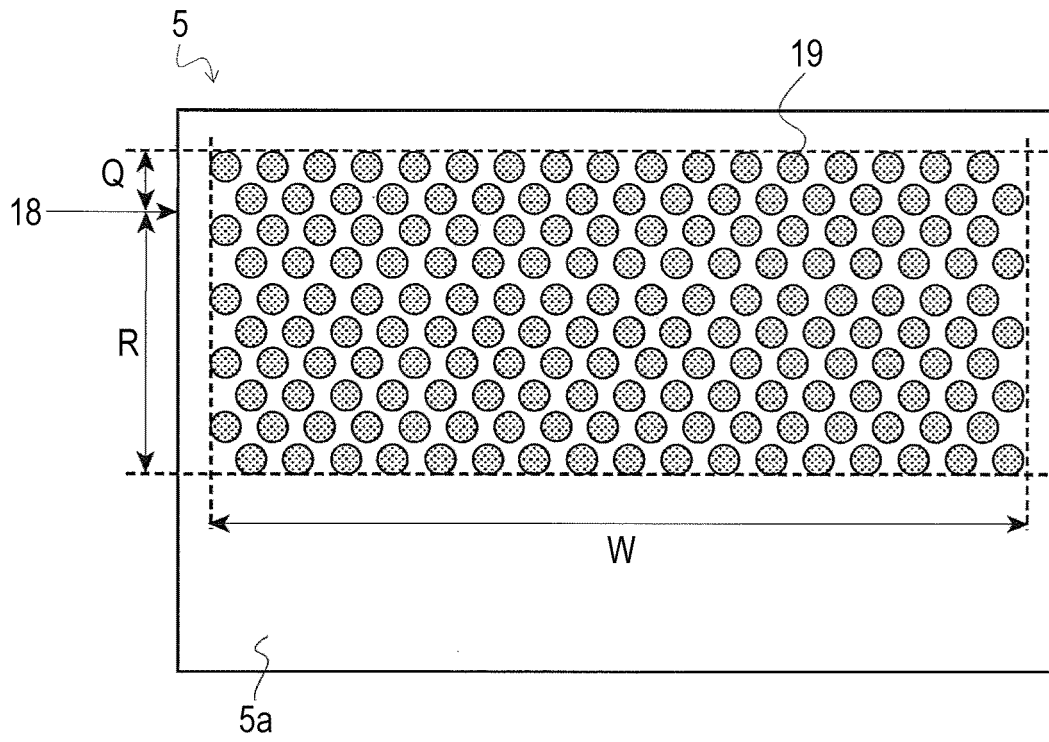
$$D1 \leq OMP = Vc \times 1000/f \quad (1)$$

$$D2 \leq 4r \quad (2)$$

In formula (2), r is the radius (mm) of a circle having a center at the center of gravity of one of the metal-filled portions with different thermal conductivity and having the same area as the one of the metal-filled portions with different thermal conductivity.

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FIG. 3



Description

Technical Field

5 **[0001]** The present invention relates to a continuous casting technique and more particularly to a continuous steel casting method with which uneven solidification of a strand at the initial stage of solidification is suppressed and which is therefore suitable for improving surface cracking and center segregation of the strand.

Background Art

10 **[0002]** Generally, when a steel strand is produced by continuous casting, molten steel poured into a mold comes into contact with the mold and is cooled, and a thin solidified layer (hereinafter referred to as a "solidifying shell") is formed. While the molten steel is poured into the mold, the solidifying shell is withdrawn downward (hereinafter referred to as "steady casting") to thereby produce the strand.

15 **[0003]** When the molten steel is cooled unevenly in the mold, the thickness of the solidifying shell becomes nonuniform, so that the surface of the solidifying shell is not smooth. In particular, when the solidifying shell with a nonuniform thickness grows at the initial stage of solidification, stress concentration occurs on the surface of the solidifying shell, and small longitudinal cracks are thereby generated. These small longitudinal cracks remain present even after complete solidification of the strand and form longitudinal cracks on the surface of the strand. When longitudinal cracks are generated
20 on the surface of the strand, it is necessary to remove the longitudinal cracks (the removal of the cracks is hereinafter referred to as "conditioning") before the strand is subjected to subsequent processes (such as a rolling process).

[0004] The mold is oscillated in a casting direction, and the oscillation of the mold causes an upper end portion of the solidifying shell to bend toward the molten steel. Then the molten steel overflows into the gap between the bent solidifying shell and an inner wall surface of the mold, and a portion projecting toward the molten steel (hereinafter referred to as
25 a "hook") is thereby formed in the solidifying shell. When the surface of the solidifying shell is not smooth, the gap formed between the bent solidifying shell and the inner wall surface of the mold is large, so that the hook of the solidifying shell is large. When the hook projecting toward the molten steel is large, non-metallic inclusions and air bubbles flowing upward in the molten steel are trapped by the hook at a meniscus (the top surface of the molten steel in the mold). The trapped non-metallic inclusions and air bubbles cause surface defects such as surface flaws and bulging in hot-rolled
30 steel sheets and cold-rolled steel sheets.

[0005] The frequency of occurrence of surface defects such as longitudinal cracks, flaws, and bulging tends to increase as the casting speed increases. At present, the casting speed of a general continuous slab casting machine is improved by a factor of about 1.5 to about 2 as compared with that of ten years ago, and the amount of repair work increases accordingly. Also in so-called hot charging and so-called direct charging that are being established technologically in
35 recent years, the repair work for the strand is a factor that inhibits stabilization of the operation. Therefore, significant economic advantages can be obtained if it is possible to prevent the formation of hooks and nonuniform growth of the thickness of the solidifying shell due to nonuniform cooling at the initial stage of solidification.

[0006] To prevent the nonuniform cooling at the initial stage of solidification, it is necessary that uniform mild cooling be performed at the initial stage of solidification to allow the thickness of the solidifying shell to grow uniformly to thereby
40 prevent the formation of hooks. In this regard, it is stated in Non Patent Literature 1 that, in order to improve the surface condition of a strand in continuous casting of a 280 × 280 mm billet, it is effective to provide projections and recesses on the inner surface of the mold. It is stated in Patent Literature 1 that recesses having a diameter or width of 3 to 80 mm and a depth of 0.1 to 1.0 mm are provided on the inner surface of a mold. It is stated in Patent Literature 2 that grooves having a width of 0.2 to 2 mm and a depth of 6 mm or less are provided on the inner surface of a mold.

45 **[0007]** These techniques are aimed at achieving mild cooling in the following manner. A mold powder is added to a meniscus portion such that a mold powder layer having a sufficient thickness is stably maintained between the mold and a solidifying shell for a long time. An air layer and a molten powder layer are thereby formed in the portion having the recesses on the inner surface of the mold, and gentle cooling (hereinafter referred to as mild cooling) is achieved by utilizing the heat-insulating ability of the air layer and the molten powder layer.

50 **[0008]** However, when these techniques are actually used for continuous casting, various problems arise. For example, a variable width mold for a continuous slab casting machine is a combination mold having wide sides and short sides. A problem in this case is that, when a recess formed on the inner surface of the mold matches the position of a corner of the mold when continuous casting is started, splashes of molten steel at the start of casting enter the recess at the corner.

55 **[0009]** Another problem is as follows. When a submerged nozzle or a tundish is replaced, the top surface of the molten steel in the mold is lower than that during steady casting. In this case, the mold powder sticking to the inner surface of the mold easily falls off and is separated, and the molten steel or splashes of the molten steel enter the recess at the corner when the casting is resumed. The phenomenon in which the molten steel enters the recess causes the occurrence of sticking-type breakout of the solidifying shell.

[0010] The mechanism of formation of center segregation in a strand is considered to be as follows. As solidification proceeds, the concentration of a segregation component increases in regions between arms of dendrite, which is a solidification structure. The molten steel with the segregation component concentrated flows out of the regions between the dendrite arms because of shrinkage of the strand during solidification or bulging of the strand. This molten steel with the segregation component concentrated flows toward a solidification completion point, i.e., a final solidification zone, and is solidified as is to form a segregation component-concentrated zone. This concentrated zone is referred to as center segregation. To prevent center segregation in a strand, it is effective at preventing the migration of molten steel in which the segregation component is concentrated and which is present in regions between dendrite arms and preventing local accumulation of the molten steel in which the segregation component is concentrated. Several methods using these principles have been proposed.

[0011] One of them is a soft reduction method for a strand using a group of reduction rolls. However, there is a limit to the effect of improving center segregation when the degree of soft reduction is slightly higher than the amount of solidification shrinkage. Patent Literature 3 proposes the following method. A strand is bulged at a point where the solid phase fraction in a central portion of the strand is 0.1 or less such that the thickness of a widthwise central portion of the strand is larger by 20 to 100 mm than the thickness of the short sides of the strand formed in the mold. Then, immediately before completion of solidification, the strand is rolled to a rolling reduction corresponding the amount of bulging using at least one pair of reduction rolls under the condition that the rolling reduction per pair of rolls is 20 mm or more.

[0012] Patent Literature 4 proposes the following method. A strand is bulged such that the thickness of a widthwise central portion of the strand is larger by 10 to 50% the thickness of the short sides of the strand until the thickness of a non-solidified portion of the strand reaches 30 mm. Then, until completion point of solidification, at least one pair of reduction rolls are used to roll the strand by an amount corresponding to the bulging amount.

[0013] Patent Literature 5 proposes the following continuous steel casting method. A strand is bulged such that the thickness of the strand is increased by 3% or more and 25% or less the thickness of the strand at the beginning of bulging, and then the resultant strand is rolled at a point where the solid phase fraction in the central portion is from 0.2 to 0.7 inclusive by the amount corresponding to 30% or more and 70% or less the bulging amount.

Citation List

Patent Literature

[0014]

PTL 1: Japanese Unexamined Patent Application Publication No. 9-94634
 PTL 2: Japanese Unexamined Patent Application Publication No. 10-193041
 PTL 3: Japanese Unexamined Patent Application Publication No. 7-210382
 PTL 4: Japanese Unexamined Patent Application Publication No. 9-206903
 PTL 5: Japanese Unexamined Patent Application Publication No. 11-99285

Non Patent Literature

[0015] NPL 1: P. Perminov et al. Steel in English, (1968) No. 7., p. 560 to 562

Summary of Invention

Technical Problem

[0016] In continuous steel casting, vertical oscillations are applied to a mold, and the oscillations prevent a solidifying shell from sticking to the mold. As a result of the oscillation of the mold, periodic recesses called oscillation marks are formed on the surface of the strand having a deformed forward end portion. When the depth of the oscillation marks is large, the surface of the solidifying shell is in uneven contact with the mold, and the amount of heat removal from the mold is also nonuniform, so that irregularities on the inner surface of the solidifying shell are also large. When the irregularities on the inner surface of the solidifying shell at the initial stage are large, the solidification interface in a final solidification zone is not smooth. A problem in this case is that, even when any of the methods described in Patent Literature 3 to Patent Literature 5 is used for rolling, its effect is not sufficiently obtained.

Solution to Problem

[0017] The present invention that solves the above problems is summarized as follows.

[1] A continuous steel casting method for producing a strand, the method including: pouring molten steel into a continuous casting mold; and simultaneously withdrawing the molten steel while the continuous casting mold is oscillated in a casting direction, wherein the continuous casting mold has a plurality of concave grooves formed on an inner wall surface of a mold copper plate in a region extending from a position at least 20 mm above the position of a meniscus in a steady casting state to a position at least 50 mm and at most 200 mm below the position of the meniscus, wherein a plurality of metal-filled portions with different thermal conductivity filled with a metal or a metal alloy having a thermal conductivity that differs by at least 20% from the thermal conductivity of the mold copper plate are disposed in the plurality of concave grooves, wherein the area fraction of the total area of the metal-filled portions with different thermal conductivity relative to the area of the inner wall surface on which the plurality of metal-filled portions with different thermal conductivity are disposed is from 10% to 80% inclusive, wherein a distance (D1) and an oscillation mark pitch (OMP) that is derived from the frequency of oscillation (f) and the speed of casting (Vc) satisfy formula (1) below, wherein a distance (D2) satisfies formula (2) below,

$$D1 \leq OMP = Vc \times 1000/f \quad (1)$$

$$D2 \leq 4r \quad (2)$$

wherein, in formula (1), Vc is the speed of casting (m/min); f is the frequency of oscillation (cpm); OMP is the oscillation mark pitch (mm); and D1 is the distance (mm) between a boundary line between a first one of the plurality of metal-filled portions with different thermal conductivity and the mold copper plate and a boundary line between a second one of the metal-filled portions with different thermal conductivity and the mold copper plate, the second one of the metal-filled portions with different thermal conductivity being located at the same position, with respect to a width direction of the mold copper plate, as the center of gravity of the first one of the metal-filled portions with different thermal conductivity and being adjacent to the first one of the metal-filled portions with different thermal conductivity in the casting direction, and wherein, in formula (2), r is the radius (mm) of a circle having a center at the center of gravity of one of the metal-filled portions with different thermal conductivity and having the same area as the one of the metal-filled portions with different thermal conductivity, and D2 is the distance (mm) between the center of gravity of the first one of the metal-filled portions with different thermal conductivity and the center of gravity of a third one of the metal-filled portions with different thermal conductivity, the third one of the metal-filled portions with different thermal conductivity being disposed at the same position, with respect to the casting direction, as the center of gravity of the first one of the metal-filled portions with different thermal conductivity and being adjacent to the first one of the metal-filled portions with different thermal conductivity in the width direction.

[2] The continuous steel casting method according to [1], wherein the plurality of metal-filled portions with different thermal conductivity are disposed such that the distance (D1) satisfies formula (3) below:

$$D1 \leq 2r. \quad (3)$$

[3] The continuous steel casting method according to [1] or [2], wherein all the plurality of concave grooves have the same shape.

[4] The continuous steel casting method according to any one of [1] to [3], wherein the plurality of concave grooves each have a circular shape or a quasi-circular shape with no corners.

[5] The continuous steel casting method according to any one of [1] to [4], wherein the plurality of metal-filled portions with different thermal conductivity are arranged in a lattice pattern.

[6] The continuous steel casting method according to any one of [1] to [4], wherein the plurality of metal-filled portions with different thermal conductivity are arranged in a staggered pattern.

[7] The continuous steel casting method according to any one of [1] to [6], the method further including: bulging mold wide sides of the strand having a non-solidified portion thereinside by a total bulging amount within the range of more than 0 mm and 20 mm or less with respect to the thickness of the strand (the thickness between the mold wide sides of the strand) at an outlet of the mold, the mold wide sides of

the strand being bulged using some of a plurality of pairs of strand support rolls provided in a continuous casting machine, a roll gap of the some of the plurality of pairs of strand support rolls being increased gradually toward a downstream side in the casting direction; and then applying a reduction force to the mold wide sides of the strand in a soft reduction zone in which the roll gap of some of the plurality of strand support rolls is reduced gradually toward the downstream side in the casting direction to thereby roll the strand to a total rolling reduction equal to or less than the total bulging amount, the reduction force being applied such that the product (mm·m/min²) of the speed of rolling (mm/min) and the speed of casting (m/min) is from 0.30 to 1.00 inclusive, the application of the reduction force being started at a point where a solid phase fraction in a thicknesswise central portion of the strand is at least 0.2 and stopped at a point where the solid phase fraction in the thicknesswise central portion reaches 0.9.

[8] The continuous steel casting method according to any one of [1] to [7], wherein a plurality of slits extending in the casting direction are disposed on an outer wall surface of the mold copper plate at a single pitch or a plurality of pitches in the width direction of the mold copper plate, wherein, when the plurality of slits are disposed at the single pitch, the single pitch is denoted by Z (mm), wherein, when the plurality of slits are disposed at the plurality of pitches, a longest one of the plurality of pitches is denoted by Z (m), and wherein Z satisfies formula (4) below:

$$Z \geq 2.5 \times D2. \quad (4)$$

[0018] The center of gravity of a metal-filled portion with different thermal conductivity is the center of gravity of a cross-sectional shape of the metal-filled portion with different thermal conductivity in a molten steel-side plane of the mold copper plate.

Advantageous Effects of Invention

[0019] In the present invention, the plurality of metal-filled portions with different thermal conductivity are disposed in the region near the meniscus and including the meniscus position and arranged in the width direction and the casting direction of the continuous casting mold, and therefore the thermal resistance of the continuous casting mold near the meniscus increases and decreases periodically in the width direction of the mold and the casting direction. In this case, a heat flux near the meniscus, i.e., a heat flux from the solidifying shell to the continuous casting mold at the initial stage of solidification increases and decreases periodically. The periodical increase and decrease of the heat flux reduces stress due to transformation from δ iron to γ iron and thermal stress, so that the deformation of the solidifying shell caused by these stresses decreases. When the deformation of the solidifying shell is small, the nonuniform heat flux distribution caused by the deformation of the solidifying shell is made uniform, and the stress generated is dispersed, so that the amount of strain decreases accordingly. Therefore, cracking of the surface of the solidifying shell can be prevented.

[0020] In the present invention, since a portion in which the heat flux increases and decreases at least once can be present per pitch of the oscillation marks, the depth of the oscillation marks can be reduced, and the surface of the solidifying shell can be made uniform. In this case, the inner surface of the solidifying shell that grows together with its surface is also made uniform, and the solidification interface in the final solidification zone is smoothened. Therefore, the number of spots to cause segregation decreases, and the internal quality of the slab strand can be improved.

Brief Description of Drawings

[0021]

Fig. 1 is a schematic side view of a vertical-bending continuous slab casting machine to which a continuous steel casting method according to an embodiment can be applied.

Fig. 2 is a graph showing an example of a roll gap profile.

Fig. 3 is a schematic side view of a mold wide side copper plate forming part of a mold installed in the continuous slab casting machine.

Fig. 4 is an illustration schematically showing thermal resistance in three locations in the mold wide side copper plate having metal-filled portions with different thermal conductivity filled with a metal having a lower thermal conductivity than the mold copper plate, the thermal resistance being shown along the positions of metal-filled portions with different thermal conductivity.

Fig. 5 shows illustrations of examples of the planar shapes of concave grooves.

Fig. 6 is a partial enlarged view of a region in which the metal-filled portions with different thermal conductivity are disposed.

Fig. 7 is a schematic illustration showing an outer wall surface side of the mold wide side copper plate.

Fig. 8 is a schematic D-D cross section of Fig. 7 with a backup plate disposed on the outer wall surface of the mold wide side copper plate, a cross section in which a stud bolt is screwed into one of bolt holes on the right side in the D-D cross section being superposed onto the D-D cross section.

Fig. 9 is an illustration showing another example of the arrangement of the metal-filled portions with different thermal conductivity.

Description of Embodiments

[0022] Specific embodiments of the present invention will be described with reference to the drawings. Fig. 1 is a schematic side view of a vertical-bending continuous slab casting machine to which a continuous steel casting method according to an embodiment can be applied.

[0023] A continuous casting mold 5 (hereinafter referred to simply as a "mold") into which molten steel 11 is poured, in which the molten steel 11 is solidified to form an outer shell shape of a strand 12, and which is oscillated in a casting direction of the strand 12 is installed in the continuous slab casting machine 1. A tundish 2 used as a relay container for supplying the molten steel 11 supplied from a ladle (not shown) to the mold 5 is disposed at a prescribed position above the mold 5. A plurality of pairs of strand support rolls including support rolls 6, guide rolls 7, and pinch rolls 8 are disposed below the mold 5. The pinch rolls 8 support the strand 12 and serve also as driving rolls for withdrawing the strand 12. Spray nozzles (not shown) such as water spray nozzles or air mist spray nozzles are disposed between strand support rolls adjacent to each other in the casting direction, and a secondary cooling zone is thereby formed. While withdrawn, the strand 12 is cooled by cooling water (hereinafter referred to as "secondary cooling water") sprayed from the spray nozzles in the secondary cooling zone. The amount of a non-solidified portion 14 inside the strand 12 thereby decreases, and a solidifying shell 13 grows during the casting performed. A sliding nozzle 3 for controlling the flow rate of the molten steel 11 is disposed on the bottom of the tundish 2, and a submerged nozzle 4 is disposed on the lower surface of the sliding nozzle 3.

[0024] A plurality of transfer rolls 9 for transferring the cast strand 12 are disposed downstream of the strand support rolls, and a strand cutter 10 for cutting the cast strand 12 into a slab strand 12a having a prescribed length is disposed above the transfer rolls 9. A soft reduction zone 17 including a plurality of pairs of guide roll groups is disposed upstream and downstream of a solidification completion position 15 of the strand 12. In the soft reduction zone 17, the roll gap of the opposed guide rolls is set so as to gradually decrease toward a downstream side in the casting direction, i.e., a roll gradient is formed.

[0025] The strand 12 can be subjected to soft reduction in the entire soft reduction zone 17 or a selected region of the soft reduction zone 17. In the present embodiment, the soft reduction zone 17 is disposed such that the solid phase fraction in a thicknesswise central portion of the strand 12 present within the installation range of the soft reduction zone 17 is from at least 0.2 to 0.9.

[0026] The reduction gradient in the soft reduction zone 17 is represented by the amount of roll gap reduction per meter in the casting direction, i.e., "mm/m," and the rolling speed (mm/min) of the strand 12 in the soft reduction zone 17 is determined as the product of the reduction gradient (mm/m) and the casting speed (m/min). Spray nozzles for cooling the strand 12 are also disposed between the strand support rolls included in the soft reduction zone 17. In the example shown in Fig. 1, only the guide rolls 7 are disposed in the soft reduction zone 17, but pinch rolls 8 may be disposed in the soft reduction zone 17. The strand support rolls disposed in the soft reduction zone 17 are referred to also as "reduction rolls."

[0027] The roll gap of the guide rolls 7 disposed between the lower end of the mold 5 and the position of a liquidus crater end of the strand 12 increases gradually every roll or every several rolls toward the downstream side in the casting direction until the amount of increase in the roll gap reaches a prescribed value. These guide rolls 7 form an intentional bulging zone 16 for intentionally bulging the mold wide sides of the strand 12 having the non-solidified portion 14 therein. The roll gap of strand support rolls disposed downstream of the intentional bulging zone 16 is reduced to a constant value or reduced so as to be commensurate with the amount of shrinkage due to the temperature decrease of the strand 12, and these strand support rolls are connected to the soft reduction zone 17.

[0028] Fig. 2 is a graph showing an example of a roll gap profile. As shown in Fig. 2, in this profile, the mold wide sides of the strand are intentionally bulged by ferrostatic pressure in the intentional bulging zone 16 to increase the thickness of central portions of the mold wide sides of the strand (region b). On the downstream side of the intentional bulging zone 16, the roll gap is constant or is reduced so as to be commensurate with the amount of shrinkage due to the temperature decrease of the strand 12 (region c), and then the mold wide sides of the strand are rolled in the soft reduction zone 17 (region d). "a" and "e" in Fig. 2 denote regions in which the roll gap is reduced so as to be commensurate with the amount of shrinkage due to the temperature decrease of the strand 12. "a" in Fig. 2 indicates an example of the roll gap in a casting method (conventional method) in which the roll gap is reduced so as to be commensurate with the amount of shrinkage due to the temperature decrease of the strand 12 with no soft reduction performed.

[0029] In the intentional bulging zone 16, the roll gap of the guide rolls 7 is gradually increased toward the downstream side in the casting direction, and the mold wide sides of the strand 12 except for portions near the short sides are intentionally bulged by the ferrostatic pressure of the non-solidified portion 14 so as to conform to the roll gap of the guide rolls 7. The portions of the mold wide sides of the strand that are located near the short sides are firmly held by the completely solidified short-side surfaces of the strand and maintain the thickness at the start of the intentional bulging. Therefore, only the intentionally bulged portions of the mold wide sides of the strand 12 come into contact with the guide rolls 7.

[0030] Fig. 3 is a schematic side view of a mold wide side copper plate forming part of the mold installed in the continuous slab casting machine. The mold 5 shown in Fig. 3 is an example of the continuous casting mold for casting a slab strand. The mold 5 is formed by combining a pair of mold wide side copper plates 5a (hereinafter referred to also as "mold copper plates") and a pair of mold short-side copper plates. Fig. 3 shows one of the mold wide side copper plates 5a. In the mold short-side copper plates, as in the mold wide side copper plates 5a, metal-filled portions with different thermal conductivity 19 are disposed on the inner wall surface side, and the description of the mold short-side copper plates will be omitted. In the strand 12, stress concentration is more likely to occur in the solidifying shell 13 on the mold wide sides of the strand because, in the shape of the strand 12, the slab width is much larger than the slab thickness, and surface cracking is more likely to occur on the mold wide sides of the strand. Therefore, the metal-filled portions with different thermal conductivity 19 may not be provided on the mold short-side copper plates of the mold 5 for a slab strand.

[0031] As shown in Fig. 3, circular metal-filled portions with different thermal conductivity 19 filled with a metal or a metal alloy having a thermal conductivity that differs by at least 20% from the thermal conductivity of the mold wide side copper plate 5a (the metal or the metal alloy is hereinafter referred to as a "different thermal conductivity metal") are disposed on an inner wall surface of the mold wide side copper plate 5a in a region extending from position Q at least 20 mm above a meniscus position 18 during steady casting to position R at least 50 mm and at most 200 mm below the meniscus position 18. Specifically, the metal-filled portions with different thermal conductivity 19 are disposed in a staggered pattern in the region having a length W in the width direction of the mold that is perpendicular to the casting direction. The "meniscus" means the "top surface of the molten steel in the mold." The "steady casting" means a steady state in which, after the start of pouring of the molten steel into the mold 5 of the continuous slab casting machine 1, the casting speed is maintained constant. During the steady casting, the speed of pouring the molten steel 11 into the mold 5 is automatically controlled by the sliding nozzle 3 and is controlled such that the meniscus position 18 is maintained constant.

[0032] The metal-filled portions with different thermal conductivity 19 are formed by filling circular concave grooves independently formed on the inner wall surface side of the mold copper plate with the different thermal conductivity metal having a thermal conductivity different from the thermal conductivity of the copper alloy forming the mold copper plate.

[0033] To fill the circular concave grooves with the different thermal conductivity metal having a thermal conductivity different from that of the copper alloy forming the mold copper plate, it is preferable to use a plating process or a thermal spraying process. To fill the circular concave grooves, the different thermal conductivity metal processed into the shape of the circular concave grooves may be fitted into the circular concave grooves. However, in this case, a gap or a crack may be formed between the different thermal conductivity metal and the mold copper plate. When a gap or a crack is formed between the different thermal conductivity metal and the mold copper plate, cracking or peeling of the different thermal conductivity metal occurs. This is not preferable because they cause a reduction in the service life of the mold, cracking of the strand, and sticking-type breakout. By filling the circular concave grooves with the different thermal conductivity metal using a plating process or a thermal spraying, the occurrence of the above problems can be prevented.

[0034] In the present embodiment, the copper alloy used for the mold copper plate may be a copper alloy containing trace amounts of chromium (Cr) and zirconium (Zr) used generally for a continuous casting mold. In recent years, to achieve uniform solidification in the mold or to prevent inclusions in the molten steel from being trapped by the solidifying shell, an electromagnetic stirrer for stirring the molten steel in the mold is generally provided. To reduce attenuation of the intensity of the magnetic field from an electromagnetic coil to the molten steel, a copper alloy with reduced electric conductivity may be used. In this case, as the electric conductivity decreases, the thermal conductivity decreases. Therefore, the thermal conductivity of the mold copper plate is about one-half the thermal conductivity of pure copper (thermal conductivity: about $400 \text{ W/(m}\cdot\text{K)}$). Generally, the copper alloy used for the mold copper plate has a lower thermal conductivity than pure copper.

[0035] Fig. 4 is an illustration schematically showing thermal resistance in three locations in the mold wide side copper plate having the metal-filled portions with different thermal conductivity filled with a metal having a lower thermal conductivity than the mold copper plate, the thermal resistance being shown along the positions of metal-filled portions with different thermal conductivity. As shown in Fig. 4, the thermal resistance is higher in the positions where the metal-filled portions with different thermal conductivity 19 are placed.

[0036] By disposing the plurality of metal-filled portions with different thermal conductivity 19 in the width direction of the continuous casting mold and the casting direction in the region near the meniscus and including the meniscus position

18, a thermal resistance distribution in which the thermal resistance of the continuous casting mold near the meniscus increases and decreases periodically in the width direction and the casting direction of the mold is formed as shown in Fig. 4. This causes a heat flux distribution in which the heat flux from the solidifying shell to the continuous casting mold increases and decreases periodically to be formed near the meniscus, i.e., in the early stage of solidification.

5 [0037] When the metal-filled portions with different thermal conductivity 19 are formed by filling the circular concave grooves with a metal having a higher thermal conductivity than the mold copper plate, the thermal resistance is lower in the positions at which the metal-filled portions with different thermal conductivity 19 are placed, in contrast to the case shown in Fig. 4. However, in this case also, as in the above case, a thermal resistance distribution in which the thermal resistance of the continuous casting mold near the meniscus increases and decreases periodically in the width direction and the casting direction of the mold is formed. To form the periodic thermal resistance distribution described above, it is preferable that the metal-filled portions with different thermal conductivity 19 are independent of each other.

10 [0038] The periodic increase and decrease in the heat flux reduces thermal stress and stress caused by phase transformation of the solidifying shell 13 (e.g., transformation from δ iron to γ iron), so that the deformation of the solidifying shell 13 caused by these stresses is reduced. When the deformation of the solidifying shell 13 is small, the nonuniform heat flux distribution caused by the deformation of the solidifying shell 13 is made uniform, and the stress generated is dispersed, so that the amount of strain decreases accordingly. The occurrence of surface cracking on the surface of the solidifying shell is thereby suppressed.

15 [0039] The periodic increase and decrease in the heat flux at the initial stage of solidification allows the thickness of the solidifying shell 13 in the mold to be made uniform not only in the width direction but also in the casting direction of the strand. When the thickness of the solidifying shell 13 in the mold is uniform, the solidification interface of the solidifying shell 13 of the strand 12 withdrawn from the mold 5 is smooth in the width direction and the casting direction of the strand even in the final solidification zone of the strand.

20 [0040] To obtain these effects stably, the periodic increase and decrease in the heat flux caused by placing the metal-filled portions with different thermal conductivity 19 must be appropriate. Specifically, when the difference between the periodic increase and decrease in the heat flux is excessively small, the effect of placing the metal-filled portions with different thermal conductivity 19 is not obtained. When the difference between the periodic increase and decrease in the heat flux is excessively large, the stress caused by the difference is large and causes surface cracking to occur.

25 [0041] The difference between the increase and decrease in the thermal flux caused by placing the metal-filled portions with different thermal conductivity 19 depends on the difference in thermal conductivity between the mold copper plate and the different thermal conductivity metal and on the area fraction of the total area of the metal-filled portions with different thermal conductivity relative to the area of the region of the inner wall surface of the mold copper plate in which region the metal-filled portions with different thermal conductivity 19 are disposed.

30 [0042] Let the thermal conductivity of the different thermal conductivity metal filled into the circular concave grooves be λ_m . In the mold copper plate used in the continuous steel casting method according to the present embodiment, the metal or metal alloy used for the mold copper plate is selected such that the ratio of the difference between the thermal conductivity (λ_m) of the different thermal conductivity metal and the thermal conductivity (λ_c) of the mold copper plate to the thermal conductivity (λ_c) of the mold copper plate, i.e., $((\lambda_c - \lambda_m)/\lambda_c) \times 100$, is 20% or more. When the metal or metal alloy used has a thermal conductivity that differs by at least 20% from the thermal conductivity (λ_c) of the copper alloy forming the mold copper plate, the effect of the periodic changes in the heat flux caused by the metal-filled portions with different thermal conductivity 19 is sufficient, and the effect of suppressing surface cracking in the strand can be sufficiently obtained even during casting of medium carbon steel and high-speed casting in which surface cracking easily occurs in the strand. The thermal conductivity of the mold copper plate and the thermal conductivity of the different thermal conductivity metal are thermal conductivities at room temperature (about 20°C). Generally, the thermal conductivity decreases as temperature increases. However, when the ratio of the difference in thermal conductivity at room temperature between the different thermal conductivity metal and the mold copper plate to the thermal conductivity of the mold copper plate at room temperature is 20% or more, the thermal resistance of locations in which the metal-filled portions with different thermal conductivity 19 are placed can differ from the thermal resistance of locations in which no metal-filled portions with different thermal conductivity 19 are placed even at the use temperature of the continuous casting mold (about 200 to about 350°C).

35 [0043] In each mold copper plate used in the continuous steel casting method according to the present embodiment, the metal-filled portions with different thermal conductivity 19 are disposed such that the area fraction ε ($\varepsilon = (B/A) \times 100$) of the ratio of the total area B (mm²) of the metal-filled portions with different thermal conductivity 19 relative to the area A ($A = (Q + R) \times W$, unit: mm²) of the region of the inner wall surface of the mold copper plate in which region the metal-filled portions with different thermal conductivity 19 are disposed is from 10% to 80% inclusive. When the area fraction ε is 10% or more, the metal-filled portions with different thermal conductivity 19 in which the heat flux is different occupy a sufficiently large area, and the heat flux in the metal-filled portions with different thermal conductivity 19 can differ from the heat flux in the mold copper plate, so that the effect of suppressing surface cracking in the strand can be obtained. When the area fraction ε exceeds 80%, the area of the metal-filled portions with different thermal conductivity 19 is

excessively large, and the period of the changes in the heat flux increases, so that the effect of suppressing surface cracking in the strand is not easily obtained.

[0044] Therefore, it is more preferable that the metal-filled portions with different thermal conductivity 19 are disposed such that the area fraction ε is from 30% to 60% inclusive. It is still more preferable that the metal-filled portions with different thermal conductivity 19 are disposed such that the area fraction ε is from 40% to 50% inclusive.

[0045] The kind of the different thermal conductivity metal is not be specified so long as the ratio of the difference between the thermal conductivity of the filling metal (λ_m) and the thermal conductivity of the mold copper plate (λ_c) is 20% or more. Reference examples of the metal usable as the filler metal include pure nickel (Ni, thermal conductivity: 90 W/(m×K)), pure chromium (Cr, thermal conductivity: 67 W/(m×K)), pure cobalt (Co, thermal conductivity: 70 W/(m×K)), and alloys containing any of these metals. These pure metals and alloys each have a lower thermal conductivity than the copper alloy and can be easily filled into the circular concave grooves using a plating process or a thermal spraying process. Pure copper having a higher thermal conductivity than the copper alloy may be used as the metal filled into the circular concave grooves. For example, when pure copper is used as the filler metal, the thermal resistance is smaller in the locations in which the metal-filled portions with different thermal conductivity 19 are disposed than in the location of the mold copper plate.

[0046] Fig. 5 shows illustrations of examples of the planar shapes of the concave grooves. In the example shown in Figs. 3 and 4, the shape of the concave grooves is a circle as shown in Fig. 5(a), but the concave grooves may not have a circular shape. For example, the concave grooves may have an elliptic shape shown in Fig. 5(b), a rounded corner square or rectangular shape shown in Fig. 5(c), or a doughnut shape shown in Fig. 5(d). The concave grooves may have a triangular shape shown in Fig. 5(e), a trapezoidal shape shown in Fig. 5(f), a pentagonal shape shown in Fig. 5(g), or a crenated shape shown in Fig. 5(h). The metal-filled portions with different thermal conductivity having a shape corresponding to the shape of the concave grooves are disposed in the concave grooves.

[0047] Preferably, the concave grooves have a circular shape shown in Fig. 5(a) or any of the shapes with no "corners" shown in Figs. 5(b) to 5(d) but may be any of the shapes with "corners" shown in Figs. 5(e) to 5(h). When the concave grooves has a shape with no "corners," the boundary surface between the different thermal conductivity metal and the mold copper plate is a curved surface. In this case, stress concentration on the boundary surface is unlikely to occur, and the occurrence of cracking on the surface of the mold copper plate is unlikely to occur.

[0048] In the present embodiment, the non-circular concave groove shapes shown in, for example, Figs. 5(b) to 5(h) are referred to as quasi-circular shapes. When the concave grooves have a quasi-circular shape, the concave grooves formed on the inner wall surface of the mold copper plate are referred to as "quasi-circular concave grooves." The radius of the quasi-circular shape is evaluated as a circle equivalent radius r that is the radius of a circle having the same area as the area of the quasi-circular shape. The circle equivalent radius r of the quasi-circular shape is computed using the following formula (5).

$$\text{Circle equivalent radius } r = (S_{ma}/\pi)^{1/2} \quad (5)$$

In formula (5), S_{ma} is the area of the quasi-circular concave groove (mm²).

[0049] Fig. 6 is a partial enlarged view of the region in which the metal-filled portions with different thermal conductivity are disposed. As shown in Fig. 6, in the mold copper plate in the present embodiment, the circular metal-filled portions with different thermal conductivity 19 are disposed in a staggered pattern. The staggered pattern means that rows of metal-filled portions with different thermal conductivity 19 are disposed alternately so as to be shifted by one-half the pitch of the metal-filled portions with different thermal conductivity 19.

[0050] In Fig. 6, 19a represents one of the metal-filled portions with different thermal conductivity, and 19b represents another one of the metal-filled portions with different thermal conductivity. The center of gravity of the metal-filled portion with different thermal conductivity 19a and the center of gravity of the metal-filled portion with different thermal conductivity 19b are disposed at the same position in the width direction of the mold copper plate and are adjacent to each other in the casting direction. The center of gravity of a metal-filled portion with different thermal conductivity 19 is the center of gravity of a cross-sectional shape of the metal-filled portion with different thermal conductivity 19 in a molten steel-side flat surface of the mold copper plate.

[0051] Let the distance in the casting direction between the boundary line between the mold copper plate and the metal-filled portion with different thermal conductivity 19a and the boundary line between the mold copper plate and the metal-filled portion with different thermal conductivity 19b be $D1$ (mm). The metal-filled portions with different thermal conductivity 19 are disposed on the inner wall surface of the mold copper plate such that the distance $D1$ satisfies the following formula (1).

$$D1 \leq OMP = V_c \times 1000/f \quad (1)$$

In formula (1), V_c is the casting speed (m/min), f is the frequency of oscillation (cpm), and OMP is the pitch of oscillation marks (mm).

[0052] As described above, the metal-filled portions with different thermal conductivity 19 are disposed in the mold copper plate such that the spacing in the casting direction between the boundary lines between the mold copper plate and metal-filled portions with different thermal conductivity 19, i.e., the spacing between the metal-filled portions with different thermal conductivity 19 in the casting direction, is smaller than the pitch of the oscillation marks in the casting direction. In this manner, since a portion in which the heat flux increases and decreases at least once can be present per pitch of the oscillation marks, a hook formed during the formation of an oscillation mark can be intentionally subjected to soft cooling at a short pitch. In this case, the nonuniform heat flux caused by the deformation of the hook is made uniform, and the amount of strain is reduced accordingly. Therefore, bending of the hooks is suppressed, and the depth of the oscillation marks can be reduced, so that the thickness of the solidifying shell 13 in the casting direction can be made uniform. By uniformizing the thickness of the solidifying shell 13 at the initial stage, the solidification interface in the final solidification zone in which center segregation is formed is smoothened, and the number of segregation spots is thereby reduced, so that the internal quality is improved. By reducing the depth of the oscillation marks, the occurrence of transverse cracks starting from the oscillation marks can be suppressed.

[0053] The metal-filled portions with different thermal conductivity 19 are disposed on the inner wall surface of the mold wide side copper plate 5a such that the distance $D1$ satisfies the following formula (3).

$$D1 \leq 2r \quad (3)$$

In formula (3), r is the radius (mm) or the circle equivalent radius (mm) of the metal-filled portions with different thermal conductivity 19.

[0054] As described above, the metal-filled portions with different thermal conductivity 19 are disposed in the mold copper plate such that the spacing in the casting direction between the metal-filled portions with different thermal conductivity 19 is at most twice the radius or the circle equivalent radius of the metal-filled portions with different thermal conductivity 19. In this case, the difference in heat flux in the casting direction is sufficient, and therefore the heat flux from the solidifying shell to the continuous casting mold at the initial stage of solidification can be periodically increased and decreased, so that the amount of strain can be reduced.

[0055] In Fig. 6, 19a represents one of the metal-filled portions with different thermal conductivity, and 19c represents another one of the metal-filled portions with different thermal conductivity. The center of gravity of the metal-filled portion with different thermal conductivity 19a and the center of gravity of the metal-filled portion with different thermal conductivity 19c are disposed at the same position in the casting direction and are adjacent to each other in the width direction of the mold copper plate. Let the distance between the center of gravity of the metal-filled portion with different thermal conductivity 19a and the center of gravity of the metal-filled portion with different thermal conductivity 19c be $D2$ (mm). The metal-filled portions with different thermal conductivity 19 are disposed on the inner wall surface of the mold wide side copper plate 5a such that the distance $D2$ satisfies the following formula (2).

$$D2 \leq 4r \quad (2)$$

In formula (2), r is the radius (mm) or the circle equivalent radius (mm) of the metal-filled portions with different thermal conductivity 19.

[0056] As described above, the metal-filled portions with different thermal conductivity 19 are disposed in the mold copper plate such that the distance from the center of gravity of the metal-filled portion with different thermal conductivity 19a to the center of gravity of the metal-filled portion with different thermal conductivity 19c is at most four times the radius of the metal-filled portions with different thermal conductivity 19. In this case, regions which are formed by the metal-filled portions with different thermal conductivity 19 and in which the heat flux increases and decreases can be present at a pitch shorter than the spatial period of solidification fluctuations in a forward end portion of the solidifying shell solidified nonuniformly. The deformation of the solidifying shell 13 at the initial stage of solidification can be reduced, and the amount of strain is reduced, so that cracking of the surface of the solidifying shell can be suppressed.

[0057] Fig. 7 is a schematic illustration showing an outer wall surface side of the mold wide side copper plate. Fig. 8 is a schematic D-D cross section of Fig. 7 with a backup plate disposed on the outer wall surface of the mold wide side copper plate, a cross section in which a stud bolt is screwed into one of bolt holes on the right side in the D-D cross

section being superposed onto the D-D cross section. A plurality of slits 30 through which cooling water 44 flows and a plurality of bolt holes 32 into which stud bolts 42 for fixing the backup plate 40 are screwed are disposed on the outer wall surface of the mold wide side copper plate 5a. The slits 30 extending in the casting direction are arranged at a plurality of pitches in the width direction of the mold wide side copper plate 5a so as not to intersect the bolt holes 32. As shown in the example in Fig. 7, in locations in which slits 30 are disposed so as not to intersect the bolt holes 32, these slits are arranged at a pitch L2. In other locations, slits 30 are arranged at a pitch L1. Here, $L2 > L1$, and the longest pitch in the example shown in Fig. 7 is L2.

[0058] The backup plate 40 is fixed to the outer wall surface of the mold wide side copper plate 5a by the stud bolts 42. The cooling water 44 is supplied from the lower side of the backup plate 40, passes through the slits 30, and is discharged from the upper side of the backup plate 40. The cooling water 44 passing through the slits 30 of the mold wide side copper plate 5a in the manner described above cools the mold wide side copper plate 5a.

[0059] The locations in which the slits 30 are disposed cause periodic fluctuations in heat flux in the width direction of the mold although the degree of the fluctuations is less than that caused by the metal-filled portions with different thermal conductivity 19. When the spatial period of the slits 30 is close to the distance D2 between the metal-filled portions with different thermal conductivity 19 in the width direction, a beat occurs in the periodic fluctuations in heat flux caused by the slits 30 and the metal-filled portions with different thermal conductivity 19. When the beat occurs, the periodic fluctuations in heat flux caused by the metal-filled portions with different thermal conductivity 19 may be disturbed.

[0060] The depth of the slits 30 and the pitch L1 are adjusted such that the magnitude of the heat flux in the regions in which slits 30 are disposed at pitch L2 so as not to intersect the bolt holes 32 is equal to the magnitude of the heat flux in other regions. Let the longest pitch of the slits 30 be Z. Then it is preferable to dispose the metal-filled portions with different thermal conductivity 19 such that the distance D2 between the metal-filled portions with different thermal conductivity 19 in the width direction satisfies the following formula (4) with respect to Z.

$$Z \geq 2.5 \times D2 \quad (4)$$

In formula (4), Z is the longest pitch (mm) of the slits 30 in the width direction of the mold wide side copper plates 5a.

[0061] In this case, the spatial period of the slits 30 is suppressed from coming close to the distance D2 between the metal-filled portions with different thermal conductivity 19 in the width direction, and the periodical fluctuations in heat flux caused by the metal-filled portions with different thermal conductivity 19 are suppressed from being disturbed.

[0062] In the example shown in Fig. 7, the slits 30 are disposed on the outer wall surface of the mold wide side copper plate 5a at the plurality of pitches, but this is not a limitation. The slits 30 may be disposed on the outer wall surface of the mold wide side copper plate 5a at a single pitch. When the slits 30 are disposed at the single pitch, the single pitch is Z (mm).

[0063] Fig. 9 is an illustration showing another example of the arrangement of the metal-filled portions with different thermal conductivity. In Fig. 9, circular metal-filled portions with different thermal conductivity 20 are disposed in a lattice pattern on the inner wall surface of the mold copper plate. The phrase "the metal-filled portions with different thermal conductivity 20 are disposed in a lattice pattern" means that the metal-filled portions with different thermal conductivity 20 are disposed at intersections of a group of parallel lines parallel to the width direction of the mold and arranged at regular intervals in the casting direction and a group of parallel lines parallel to the casting direction and arranged at regular intervals in the width direction of the mold.

[0064] In Fig. 9, one of the metal-filled portions with different thermal conductivity is denoted by 20a, other metal-filled portions with different thermal conductivity are denoted by 20b and 20c. The center of gravity of the metal-filled portion with different thermal conductivity 20a and the center of gravity of the metal-filled portion with different thermal conductivity 20b are disposed at the same position in the width direction of the mold copper plate and disposed at positions adjacent to each other in the casting direction. The center of gravity of the metal-filled portion with different thermal conductivity 20a and the center of gravity of the metal-filled portion with different thermal conductivity 20c are disposed at the same position in the casting direction and are disposed at positions adjacent to each other in the width direction of the mold copper plate.

[0065] In Fig. 9, a distance D1 is the distance in the casting direction from the boundary line between the metal-filled portion with different thermal conductivity 20a and the mold copper plate to the boundary line between the metal-filled portion with different thermal conductivity 20b and the mold copper plate. A distance D2 is the distance from the center of gravity of the metal-filled portion with different thermal conductivity 20a to the center of gravity of the metal-filled portion with different thermal conductivity 20c. In Fig. 9, the metal-filled portions with different thermal conductivity 20 are disposed on the inner wall surface of the mold wide side copper plate 5a such that the above formulas (1), (2), and (3) are satisfied.

[0066] As described above, the metal-filled portions with different thermal conductivity may be disposed in a lattice

pattern on the mold copper plate. Even when the metal-filled portions with different thermal conductivity are disposed in the lattice pattern, hooks are suppressed from being bent when the above formula (1) is satisfied. In this case, the depth of oscillation marks can be reduced, and the same effects as those when the metal-filled portions with different thermal conductivity are disposed in a staggered pattern can be obtained.

[0067] In the examples shown in the present embodiment, all the concave grooves disposed in the mold copper plate have the same circular shape, but this is not a limitation. It is not necessary that all the concave grooves have the same shape at least when the above-described area fraction is from 10% to 80% inclusive and formulas (1) and (2) are satisfied,

[0068] By combining the mold having the metal-filled portions with different thermal conductivity 19 and the method including intentionally bulging a strand by an amount of more than 0 mm and 20 mm or less and then subjecting the resulting strand having a central portion with a solid phase fraction of from 0.2 to 0.9 inclusive to soft reduction by an amount equal to or less than the bulging amount of the strand during the intentional bulging while a reduction force is applied such that the product ($\text{m} \cdot \text{mm}/\text{min}^2$) of the rolling speed (mm/min) and the casting speed (m/min) is from 0.30 to 1.00 inclusive, the internal quality of the strand can be further improved.

[0069] In the present embodiment, the total amount of intentional bulging in the intentional bulging zone 16 (hereinafter referred to as the "total bulging amount") is within the range of more than 0 mm and 20 mm or less with respect to the thickness of the strand (the thickness between the mold wide sides of the strand) at the outlet of the mold. In the present embodiment, the initial solidification in the mold is controlled, and therefore even the solidification interface in the final solidification zone of the strand 12 can be smoothened in both the width direction and the casting direction of the strand. Therefore, the reduction force during soft reduction is uniformly applied to the solidification interface, and therefore the center segregation can be reduced even when the total bulging amount is more than 0 mm and 20 mm or less.

[0070] In the soft reduction zone 17, the rolling of the strand 12 is started at a point where the solid phase fraction in the thicknesswise central portion of the strand is at least 0.2 and stopped at a point where the solid phase fraction reaches 0.9. If the rolling of the strand 12 is started at a point where the solid phase fraction in the central portion is less than 0.2, center segregation again occurs as the solidification proceeds because the thickness of the non-solidified portion of the strand at a rolling position immediately after the start of the rolling is large. If the strand is still rolled at a point where the solid phase fraction of the central portion is 0.9 or more, the molten steel in which a segregation component is concentrated is not easily discharged, and the effect of improving center segregation is small. This is because, since the thickness of the solidifying shell 13 of the strand during rolling is large, the reduction force does not reach the central portion sufficiently. When the solid phase fraction of the central portion exceeds 0.9 and the rolling reduction is large, positive segregation occurs near the thicknesswise central portion as described above. Therefore, the strand is rolled at the positions in which the solid phase fraction in the central portion is from 0.2 to 0.9 inclusive. Of course, the strand 12 may be rolled in the soft reduction zone 17 before the solid phase fraction in the thicknesswise central portion of the strand reaches 0.2 and after the solid phase fraction in the thicknesswise central portion of the strand exceeds 0.9.

[0071] The solid phase fraction in the thicknesswise central portion of the strand can be determined by two-dimensional heat transfer solidification computation. The solid phase fraction is defined to be 0 at the liquidus temperature of the steel or higher and is defined to be 1.0 at the solidus temperature of the steel or lower. The position at which the solid phase fraction in the thicknesswise central portion of the strand is 1.0 is the solidification completion position 15, and the solidification completion position 15 corresponds to the most downstream position at which the solid phase fraction in the thicknesswise central portion of the strand moving toward the downstream side reaches 1.

[0072] In the present embodiment, the total amount of rolling reduction (hereinafter referred to as the "total rolling reduction") of the strand 12 in the soft reduction zone 17 is equal to the total bulging amount or less than the total bulging amount. When the total rolling reduction is equal to the total bulging amount or less than the total bulging amount, a portions on each short-side side of the strand 12 in which portion the thicknesswise central portion has been completely solidified is not rolled. Therefore, the load on the guide rolls 7 included in the soft reduction zone 17 is reduced, and facility troubles such as damage to bearings for the guide rolls 7 and breakage of the guide rolls 7 can be suppressed.

[0073] In the present embodiment, when the strand is subjected to soft reduction in the soft reduction zone 17, a reduction force is applied to the mold wide sides of the strand such that the product of the rolling speed and the casting speed ($\text{m} \cdot \text{mm}/\text{min}^2$) is from 0.30 to 1.00 inclusive. When the strand is rolled to a rolling reduction which corresponds to the product of the rolling speed and the casting speed is less than 0.30, the thickness of the non-solidified portion of the strand at a rolling position after the start of rolling is large, and the molten steel in which the segregation component is concentrated is not sufficiently discharged from areas between arms of dendrite. Therefore, center segregation again occurs after rolling. When the strand is rolled to a rolling reduction which corresponds to the product of the rolling speed and the casting speed exceeding 1.00, almost all the molten steel in which the segregation component is concentrated and which is present in areas between dendrite arms is squeezed out and discharged to the upstream side in the casting direction. However, since the thickness of the non-solidified portion is small, the segregation component is trapped by the solidifying shell on the opposite sides in the thickness direction of the strand at a position slightly upstream of the rolling position in the casting direction, and therefore positive segregation occurs near the widthwise central portion of the strand.

[0074] The effect of the soft reduction on the prevention of the occurrence of center segregation in the central portion of the strand and positive segregation near the central portion is affected by the solidification structure of the strand. The effect of the reduction is small when the solidification structure of a portion in contact with the non-solidified portion is an isometric crystal structure because the concentrated molten steel causing semi-macro segregation is present between portions having the isometric crystal structure. Therefore, it is preferable that the solidification structure is not the isometric crystal structure but is a columnar crystal structure.

[0075] In the present embodiment, the thickness of the solidifying shell 13 and the solid phase fraction in the thicknesswise central portion of the strand are determined in advance using, for example, two-dimensional heat transfer solidification computation under various casting conditions for the continuous casting operation. To allow the strand to be rolled in the soft reduction zone 14 from the point where the solid phase fraction in the thicknesswise central portion of the strand is at least 0.2 until the point where the solid phase fraction reaches 0.9, one or two or more of the amount of secondary cooling water, the amount of reduction in margin of secondary cooling, and the casting speed are adjusted. The "reduction in margin of secondary cooling" means that spraying of the cooling water onto both edges of the mold wide sides of the strand is stopped. When the reduction in margin of secondary cooling is performed, the secondary cooling is weakened, and the solidification completion position 13 is generally shifted toward the downstream side in the casting direction.

[0076] As described above, by performing the continuous steel casting method according to the present embodiment, cracking of the surface of the strand caused by nonuniform cooling of the solidifying shell at the initial stage of solidification can be prevented, and the depth of the oscillation marks can also be reduced. By reducing the depth of the oscillation marks to make the surface of the solidifying shell 13 uniform at the initial stage, the solidification interface in the final solidification zone is also smoothened. By subjecting the strand to intentional bulging and soft reduction, the reduction force can be uniformly applied to the solidification interface, and the occurrence of center segregation in the thicknesswise central portion of the strand can be suppressed. This allows a high-quality stand to be produced stably.

[0077] The above description relates to continuous casting of the slab strand. However, the continuous steel casting method according to the present embodiment is not limited to the continuous casting of the slab strand and is applicable to continuous casting of a bloom strand or a billet strand in the manner described above.

Example 1

[0078] The following tests were performed. Medium carbon steel (chemical composition, C: 0.08 to 0.17% by mass, Si: 0.10 to 0.30% by mass, Mn: 0.50 to 1.20% by mass, P: 0.010 to 0.030% by mass, S: 0.005 to 0.015% by mass, Al: 0.020 to 0.040% by mass) was cast using water-cooled copper molds prepared by disposing a metal on their inner wall surfaces under various conditions. When the medium carbon steel was cast, the total bulging amount in the intentional bulging zone and the product of the rolling speed in the soft reduction zone and the casting speed were changed variously. Then surface cracking of the cast strands and their internal quality (center segregation) were examined.

[0079] In all the tests, the product of the rolling speed in the soft reduction zone and the casting speed was 0.28 to 0.90 mm·m/min², and the strand was rolled in the soft reduction zone from the point where the solid phase fraction in the thicknesswise central portion of the strand was at least 0.2 until the point where the solid phase fraction in the thicknesswise central portion reached 0.9. The total rolling reduction when the strand was intentionally bulged in the intentional bulging zone was set to be equal to or less than the total bulging amount. In a test in which a strand was not bulged in the intentional bulging zone, solidification completion positions on the short-side sides of the strand were also rolled in the soft reduction zone.

[0080] Each of the molds used has an inner space size with a wide side length of 2.1 m and a short-side length of 0.26 m. The length of each of the water-cooled copper molds used from the upper end to the lower end (= the length of the mold) is 950 mm. The position of the meniscus (the top surface of the molten steel in the mold) during steady casting was set to a position 100 mm below the upper end of the mold. To understand the effects of the continuous steel casting method according to the present embodiment, the molds were produced under the following conditions, and comparative tests were performed. In all the molds, a metal having a lower thermal conductivity than the thermal conductivity of the mold copper plate was used as the different thermal conductivity metal. The metal-filled portions with different thermal conductivity 19 each have a $\phi 6$ mm disk shape. In the casting conditions used, the oscillation mark pitch was 13 mm.

Mold 1: A region extending from a position 80 mm below the upper end of the mold to a position 300 mm below the upper end of the mold (the length of the region = 220 mm) was filled with a different thermal conductivity metal having a thermal conductivity different by 20% from the thermal conductivity of copper to thereby dispose metal-filled portions with different thermal conductivity 19 arranged in a staggered pattern. The area fraction ε of the metal-filled portions with different thermal conductivity 19 is 50%. The distance D1 between the metal-filled portions with different thermal conductivity 19 in the casting direction is 6 mm, and the distance D2 between the centers of gravity of metal-filled portions with different thermal conductivity 19 in the width direction of the mold is 12 mm. The longest

upper end of the mold was filled with a different thermal conductivity metal having a thermal conductivity different by 20% from the thermal conductivity of copper to thereby dispose metal-filled portions with different thermal conductivity 19 arranged in a staggered pattern. The area fraction ε of the metal-filled portions with different thermal conductivity 19 is 50%. The distance D1 between the metal-filled portions with different thermal conductivity 19 in the casting direction is 9 mm, and the distance D2 between the centers of gravity of metal-filled portions with different thermal conductivity 19 in the width direction of the mold is 12 mm. The longest pitch of slits 30 disposed on outer wall surfaces of the mold is 33.0 mm.

Mold 10: A region extending from a position 80 mm below the upper end of the mold to a position 300 mm below the upper end of the mold was filled with a different thermal conductivity metal having a thermal conductivity different by 20% from the thermal conductivity of copper to thereby dispose metal-filled portions with different thermal conductivity 19 arranged in a staggered pattern. The area fraction ε of the metal-filled portions with different thermal conductivity 19 is 50%. The distance D1 between the metal-filled portions with different thermal conductivity 19 in the casting direction is 9 mm, and the distance D2 between the centers of gravity of metal-filled portions with different thermal conductivity 19 in the width direction of the mold is 12 mm. The longest pitch of slits 30 disposed on outer wall surfaces of the mold is 16.5 mm.

Mold 11: This is a mold having no metal-filled portions with different thermal conductivity 19.

[0081] The mold powder used in the continuous casting operation was a mold powder having a basicity ((% by mass of CaO)/(% by mass of SiO₂)) of 1.1, a solidification temperature of 1,090°C, and a viscosity coefficient at 1,300°C of 0.15 Pa·s. The solidification temperature is a temperature at which the viscosity coefficient of the mold powder increases rapidly during cooling of the molten mold powder. The meniscus position in the mold during steady casting is located at a position 100 mm below the upper end of the mold. During casting, the meniscus position was controlled such that the meniscus was present within the installation range of the metal-filled portion with different thermal conductivity 19. The casting speed during steady casting is 1.7 to 2.2 m/min. In all the test strands cast for examining surface cracking and internal quality, the casting speed during casting was 2.0 m/min. The degree of superheat of the molten steel in the tundish is 25 to 35°C. To control the temperature of the mold, a thermocouple was embedded into a position 50 mm below the meniscus in the mold at a depth of 5 mm from a surface (the surface on the molten steel side) from the rear side, and the surface temperature of the mold was estimated from the measurement value of the copper plate temperature by the thermocouple.

[0082] After completion of the continuous casting, the mold wide sides of each strand were washed with acid to remove scale, and the number of surface cracks generated was measured. The occurrence of the surface cracks in the strand was evaluated using a value computed using the length of the tested strand in the casting direction as a denominator and the length, in the casting direction, of a portion of the strand in which the surface cracks occurred as a numerator. To evaluate the internal quality (center segregation) of the strand, a transverse cross-sectional sample was taken from the strand and mirror-polished. The concentration of Mn in a region ± 10 mm from the center of the mirror-polished surface of the transverse cross-sectional sample was measured every 100 μm using an EPMA to evaluate the degree of segregation. Specifically, in the evaluation, the ratio (C/C_0) of the average concentration of Mn (C) in the region ± 10 mm from the central portion to the concentration of Mn (C_0) at an edge portion considered to have no segregation was defined as the degree of segregation of Mn.

[0083] Separately from these examinations, the nonuniformity in the thickness of the solidifying shell σ (mm) was measured under the conditions of each test level. To measure the nonuniformity in the thickness of the solidifying shell, FeS (iron sulfide) powder was added to the molten steel in the mold, and a sulfur print was prepared on a cross section of the strand obtained to thereby measure the thickness of the solidifying shell. The thickness of the solidifying shell was measured at a position one-fourth the width in the width direction of the strand from the meniscus position until a position 200 mm below the meniscus position in 40 points at a 5 mm pitch. To compute σ , the following formula (6) was used. [Math 1]

$$\sigma = \frac{\sum \sqrt{(D - D_i)^2}}{N} \dots (6)$$

In formula (6), D is the actually measured value (mm) of the thickness of the solidifying shell, and D_i is a computational value of the thickness of the solidifying shell (mm) computed from solidification time corresponding to the distance from the meniscus to the position of the measurement of the thickness of the solidifying shell using an approximate formula defining the relation between the thickness of the solidifying shell and the solidification time. N is the number of measurements and is 40 in this Example.

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[0084] Table 1 shows the test conditions for test levels 1 to 14 and the results of examination of the surfaces of the strands and their internal quality.

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[Table 1]

Test level	Mold type	Strand size (Thickness × width)	Casting speed (m/min)	Distance from upper end			OSC pitch (mm)	Casting direction	Width direction (mm)	Surface plating area fraction (%)	Ratio of difference in thermal conductivity between mold material and surface plating (%)	Soft reduction condition		Quality evaluation		Nonuniformity in thickness of solidifying shell σ (mm)	Longest slit pitch Z (mm)	Remarks
				Meniscus position	Plating start position	Plating finish position						Amount of intentional bulging (mm)	Rolling speed × casting speed (mm·m/min ²)	Surface cracking ratio (%)	Center segregation (C/Co)			
1	1	250×210 ₀	2.0	100	80	300	13	6	12	50	20	0	0.28	0.0	Slight 1.04	0.30	33.0	Inventive Example
2	2	250×210 ₀	2.0	100	190	750	13	6	12	50	20	0	0.28	25.0	Unsuitable 1.08	0.38	33.0	Comparative Example
3	3	250×210 ₀	2.0	100	80	300	13	15	12	50	20	0	0.28	2.5	Unsuitable 1.07	0.37	33.0	Comparative Example
4	4	250×210 ₀	2.0	100	80	300	13	6	15	50	20	0	0.28	16.0	Slight 1.03	0.31	38.0	Comparative Example
5	5	250×210 ₀	2.0	100	80	300	13	6	12	50	15	0	0.28	13.0	Slight 1.04	0.32	33.0	Comparative Example
6	6	250×210 ₀	2.0	100	80	300	13	6	12	5	20	0	0.28	18.0	Slight 1.05	0.33	33.0	Comparative Example
7	7	250×210 ₀	2.0	100	80	300	13	6	12	85	20	0	0.28	12.0	Slight 1.04	0.31	33.0	Comparative Example
8	1	250×210 ₀	2.0	100	80	300	13	6	12	50	20	3	0.90	0.0	Good 1.01	0.25	33.0	Inventive Example

(continued)

Test level	Mold type	Strand size (Thickness × width)	Casting speed (m/min)	Distance from upper end			OSC pitch (mm)	Casting direction	Width direction	Surface plating area fraction (%)	Ratio of difference in thermal conductivity between mold material and surface plating (%)	Soft reduction condition		Quality evaluation		Nonuniformity in thickness of solidifying shell σ (mm)	Longest slit pitch Z (mm)	Remarks
				Meniscus position	Plating start position	Plating finish position						Amount of intentional bulging (mm)	Rolling speed × casting speed (mm·m/min ²)	Surface crack ing ratio (%)	Center segregation (C/Co)			
9	1	250×210 ₀	2.0	100	80	300	13	6	12	50	20	2	0.90	0.0	Good 1.02	0.27	33.0	Inventive Example
10	1	250×210 ₀	2.0	100	80	300	13	6	12	50	20	0	0.90	0.0	Good 1.02	0.27	33.0	Inventive Example
11	1	250×210 ₀	2.0	100	80	300	13	6	12	50	20	20	0.30	0.0	Good 1.01	0.25	33.0	Inventive Example
12	3	250×210 ₀	2.0	100	80	300	13	15	12	50	20	0	0.50	0.0	Slight 1.03	0.37	33.0	Comparative Example
13	8	250×210 ₀	2.0	100	80	300	13	6	12	50	20	3	0.90	1.0	Slight 1.03	0.29	33.0	Inventive Example
14	9	250×210 ₀	2.0	100	80	300	13	9	12	50	20	0	0.28	1.8	Slight 1.05	0.31	33.0	Inventive Example
15	10	250×210 ₀	2.0	100	80	300	13	9	12	50	20	0	0.28	1.5	Slight 1.04	0.33	16.5	Inventive Example
16	11	250×210 ₀	2.0	-	-	-	13	-	-	-	-	3	0.90	30.0	Slight 1.05	0.32	33.0	Comparative Example

[0085] In test levels 1, 8, 9, 10, 11, and 13, the conditions for the placement of the metal-filled portions with different thermal conductivity 19 on the surfaces of the mold were within the range of the present invention, and the longest pitch of the slits 30 satisfies formula (4). In all these test levels, the ratio of surface cracking was improved significantly. The nonuniformity in the thickness of the solidifying shell was 0.30 or less, and the thickness of the solidifying shell was uniform. However, in test level 1, the product of the rolling speed and the casting speed was outside the range of from 0.30 to 1.00, and slight center segregation was found. In the results in other levels, the center segregation was improved.

[0086] In test level 2, the range in which the metal-filled portions with different thermal conductivity 19 were placed was shifted downward, and the product of the rolling speed and the casting speed was outside the range of from 0.30 to 1.00. Therefore, in test level 2, fine surface cracks were formed in the strand, and the effect of reducing surface cracking was not found, as in conventional cases. The degree of nonuniformity in the thickness of the solidifying shell was large, 0.38 mm, and the effect of improving center segregation was not obtained either.

[0087] In test level 3, the distance D1 in the casting direction was long, and the product of the rolling speed and the casting speed was outside the range of from 0.30 to 1.00. In test level 3, the surface cracking of the strand was improved. However, the degree of nonuniformity in the thickness of the solidifying shell was large, 0.37 mm, and the effect of improving center segregation was not obtained either.

[0088] In test level 4, the distance D2 in the width direction of the mold was long, and the product of the rolling speed and the casting speed was outside the range of from 0.30 to 1.00. In test level 4, surface cracking was found in the strand, and the effect of improving surface cracking was not obtained. The degree of nonuniformity in the thickness of the solidifying shell was also slightly large, 0.31 mm, and slight center segregation was also found.

[0089] In test level 5, the ratio of the difference in thermal conductivity between copper and the different thermal conductivity metal was less than 20%. In test level 6, the area fraction of the metal-filled portions with different thermal conductivity 19 was less than 10%. In test level 7, the area fraction of the metal-filled portions with different thermal conductivity 19 was higher than 80%. Therefore, in these test levels 5 to 7, surface cracking was found in the strand, and the effect of improving surface cracking was not obtained. The degree of nonuniformity in the thickness of the solidifying shell was also slightly large, 0.31 to 0.33, and slight center segregation was also found.

[0090] In test level 12, the product of the rolling speed and the casting speed was within the range of from 0.30 to 1.00, but the distance D1 in the casting direction was long. In test level 12, surface cracking and center segregation in the strand were improved, but the degree of nonuniformity in the thickness of the solidifying shell was large, 0.37 mm.

[0091] In test level 14, the conditions for the placement of the metal-filled portions with different thermal conductivity 19 on the surfaces of the mold were within the range of the present invention, and the longest pitch Z of the slits 30 satisfies formula (4). However, the distance D1 in the casting direction was long. Although formula (1) is satisfied, formula (3) is not satisfied. Therefore, although the ratio of surface cracking was better than that in test levels 2 to 7, the ratio of surface cracking was slightly large, 1.8%, and slight center segregation was found. The degree of nonuniformity in the thickness of the solidifying shell was also slightly large, 0.31 mm.

[0092] In test level 15, the conditions for the placement of the metal-filled portions with different thermal conductivity 19 on the surfaces of the mold were within the range of the present invention, but the longest pitch Z of the slits 30 does not satisfy formula (4). The distance D1 in the casting direction was long. Although formula (1) is satisfied, formula (3) is not satisfied. Therefore, although the ratio of surface cracking was better than that in test levels 2 to 7, the ratio of surface cracking was slightly large, 1.5%. Slight center segregation was found, and the degree of nonuniformity in the thickness of the solidifying shell was also slightly large, 0.33 mm.

[0093] In test level 16, since no metal-filled portions with different thermal conductivity 19 were provided, surface cracking was found in the strand. The degree of nonuniformity in the thickness of the solidifying shell was also slightly large, 0.32 mm, and center segregation was also found.

Reference Signs List

[0094]

- 1 continuous slab casting machine
- 2 tundish
- 3 sliding nozzle
- 4 submerged nozzle
- 5 continuous casting mold
- 5a mold wide side copper plate
- 6 support roll
- 7 guide roll
- 8 pinch roll
- 9 transfer roll

10 strand cutter
 11 molten steel
 12 strand
 12a slab strand
 5 13 solidifying shell
 14 non-solidified portion
 15 solidification completion position
 16 intentional bulging zone
 17 soft reduction zone
 10 18 meniscus position
 19 metal-filled portion with different thermal conductivity
 19a one of metal-filled portions with different thermal conductivity
 19b another one of metal-filled portions with different thermal conductivity
 19c another one of metal-filled portions with different thermal conductivity
 15 20 metal-filled portion with different thermal conductivity
 20a one of metal-filled portions with different thermal conductivity
 20b another one of metal-filled portions with different thermal conductivity
 20c another one of metal-filled portions with different thermal conductivity
 30 slit
 20 32 bolt hole
 40 backup plate
 42 stud bolt
 44 cooling water

Claims

1. A continuous steel casting method for producing a strand, the method comprising: pouring molten steel into a continuous casting mold; and simultaneously withdrawing the molten steel while the continuous casting mold is oscillated in a casting direction,
- wherein the continuous casting mold has a plurality of concave grooves formed on an inner wall surface of a mold copper plate in a region extending from a position at least 20 mm above the position of a meniscus in a steady casting state to a position at least 50 mm and at most 200 mm below the position of the meniscus,
- wherein a plurality of metal-filled portions with different thermal conductivity filled with a metal or a metal alloy having a thermal conductivity that differs by at least 20% from the thermal conductivity of the mold copper plate are disposed in the plurality of concave grooves, wherein the area fraction of the total area of the metal-filled portions with different thermal conductivity relative to the area of the inner wall surface on which the plurality of metal-filled portions with different thermal conductivity are disposed is from 10% to 80% inclusive,
- wherein a distance (D1) and an oscillation mark pitch (OMP) that is derived from the frequency of oscillation (f) and the speed of casting (Vc) satisfy formula (1) below, wherein a distance (D2) satisfies formula (2) below,

$$D1 \leq OMP = Vc \times 1000/f \quad (1)$$

$$D2 \leq 4r \quad (2)$$

wherein, in formula (1),

Vc is the speed of casting (m/min);

f is the frequency of oscillation (cpm);

OMP is the oscillation mark pitch (mm); and

D1 is the distance (mm) between a boundary line between a first one of the plurality of metal-filled portions with different thermal conductivity and the mold copper plate and a boundary line between a second one of the metal-filled portions with different thermal conductivity and the mold copper plate, the second one of the metal-filled portions with different thermal conductivity being located at the same position, with respect to a width direction of the mold copper plate, as the center of gravity of the first one of the metal-filled portions with different

thermal conductivity and being adjacent to the first one of the metal-filled portions with different thermal conductivity in the casting direction, and

wherein, in formula (2), r is the radius (mm) of a circle having a center at the center of gravity of one of the metal-filled portions with different thermal conductivity and having the same area as the one of the metal-filled portions with different thermal conductivity, and

D_2 is the distance (mm) between the center of gravity of the first one of the metal-filled portions with different thermal conductivity and the center of gravity of a third one of the metal-filled portions with different thermal conductivity, the third one of the metal-filled portions with different thermal conductivity being disposed at the same position, with respect to the casting direction, as the center of gravity of the first one of the metal-filled portions with different thermal conductivity and being adjacent to the first one of the metal-filled portions with different thermal conductivity in the width direction.

2. The continuous steel casting method according to claim 1, wherein the plurality of metal-filled portions with different thermal conductivity are disposed such that the distance (D_1) satisfies formula (3) below:

$$D_1 \leq 2r. \quad (3)$$

3. The continuous steel casting method according to claim 1 or 2, wherein all the plurality of concave grooves have the same shape.
4. The continuous steel casting method according to any one of claims 1 to 3, wherein the plurality of concave grooves each have a circular shape or a quasi-circular shape with no corners.
5. The continuous steel casting method according to any one of claims 1 to 4, wherein the plurality of metal-filled portions with different thermal conductivity are arranged in a lattice pattern.
6. The continuous steel casting method according to any one of claims 1 to 4, wherein the plurality of metal-filled portions with different thermal conductivity are arranged in a staggered pattern.
7. The continuous steel casting method according to any one of claims 1 to 6, the method further comprising:

bulging mold wide sides of the strand having a non-solidified portion thereinside by a total bulging amount within the range of more than 0 mm and 20 mm or less with respect to the thickness of the strand (the thickness between the mold wide sides of the strand) at an outlet of the mold, the mold wide sides of the strand being bulged using some of a plurality of pairs of strand support rolls provided in a continuous casting machine, a roll gap of the some of the plurality of pairs of strand support rolls being increased gradually toward a downstream side in the casting direction; and

then applying a reduction force to the mold wide sides of the strand in a soft reduction zone in which the roll gap of some of the plurality of strand support rolls is reduced gradually toward the downstream side in the casting direction to thereby roll the strand to a total rolling reduction equal to or less than the total bulging amount, the reduction force being applied such that the product ($\text{mm} \cdot \text{m}/\text{min}^2$) of the speed of rolling (mm/min) and the speed of casting (m/min) is from 0.30 to 1.00 inclusive, the application of the reduction force being started at a point where a solid phase fraction in a thicknesswise central portion of the strand is at least 0.2 and stopped at a point where the solid phase fraction in the thicknesswise central portion reaches 0.9.

8. The continuous steel casting method according to any one of claims 1 to 7, wherein a plurality of slits extending in the casting direction are disposed on an outer wall surface of the mold copper plate at a single pitch or a plurality of pitches in the width direction of the mold copper plate, wherein, when the plurality of slits are disposed at the single pitch, the single pitch is denoted by Z (mm), wherein, when the plurality of slits are disposed at the plurality of pitches, a longest one of the plurality of pitches is denoted by Z (mm), and wherein Z satisfies formula (4) below:

$$Z \geq 2.5 \times D2. \quad (4)$$

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FIG. 1

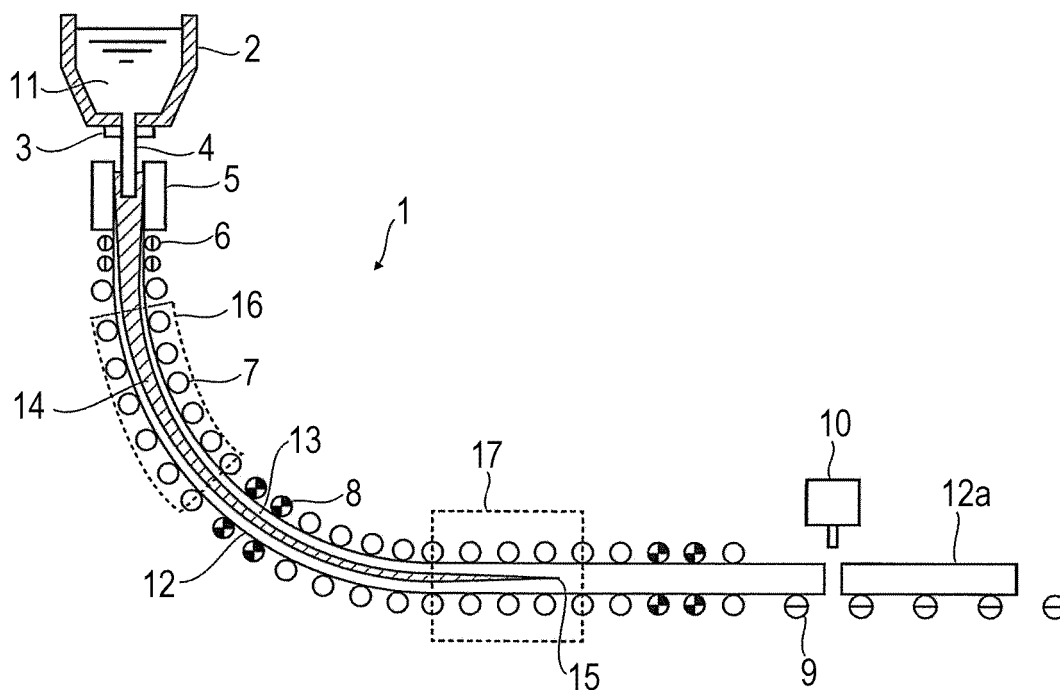


FIG. 2

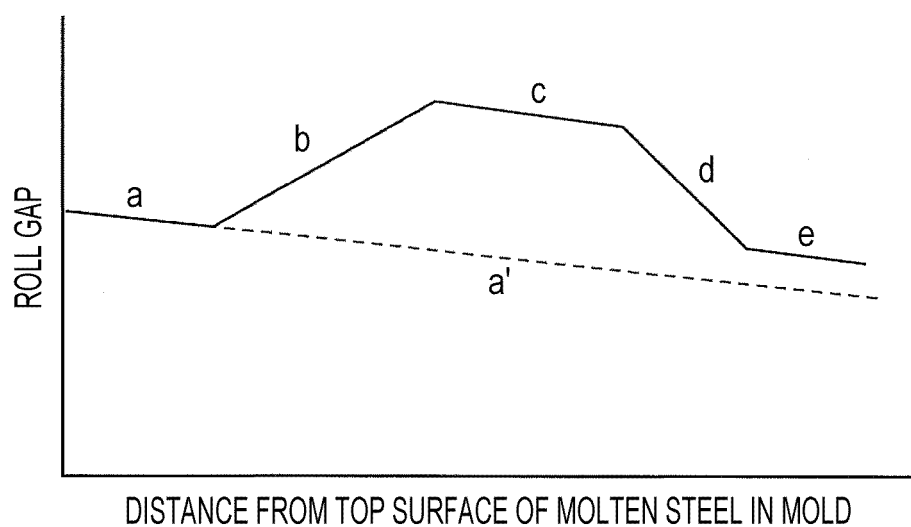


FIG. 3

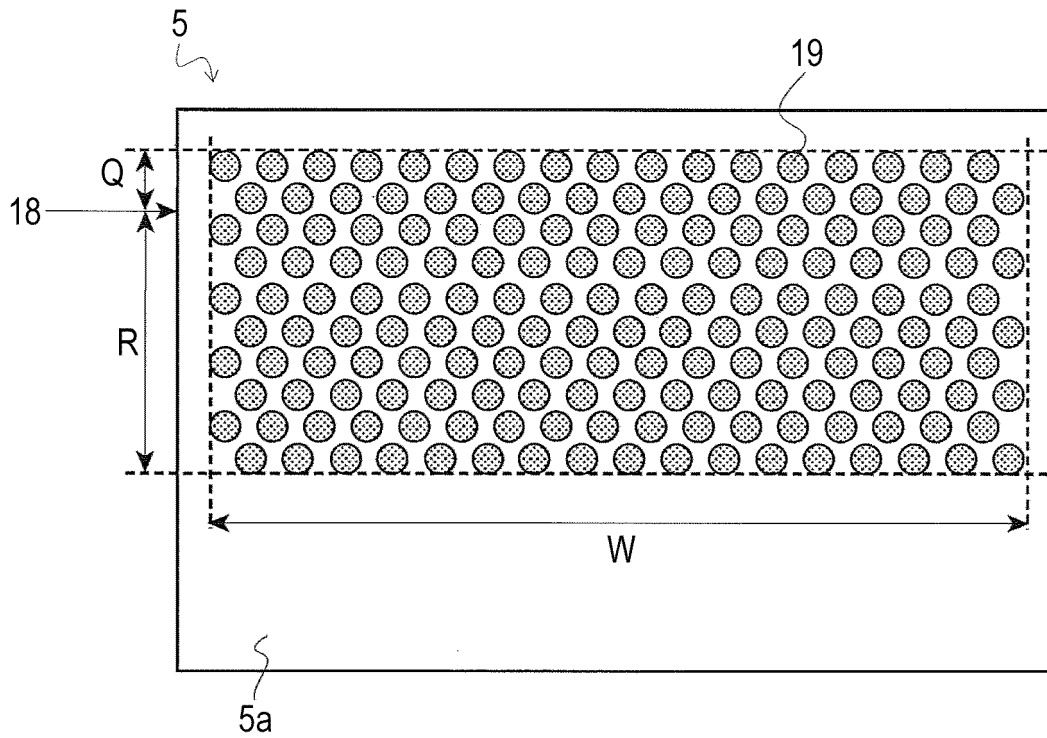


FIG. 4

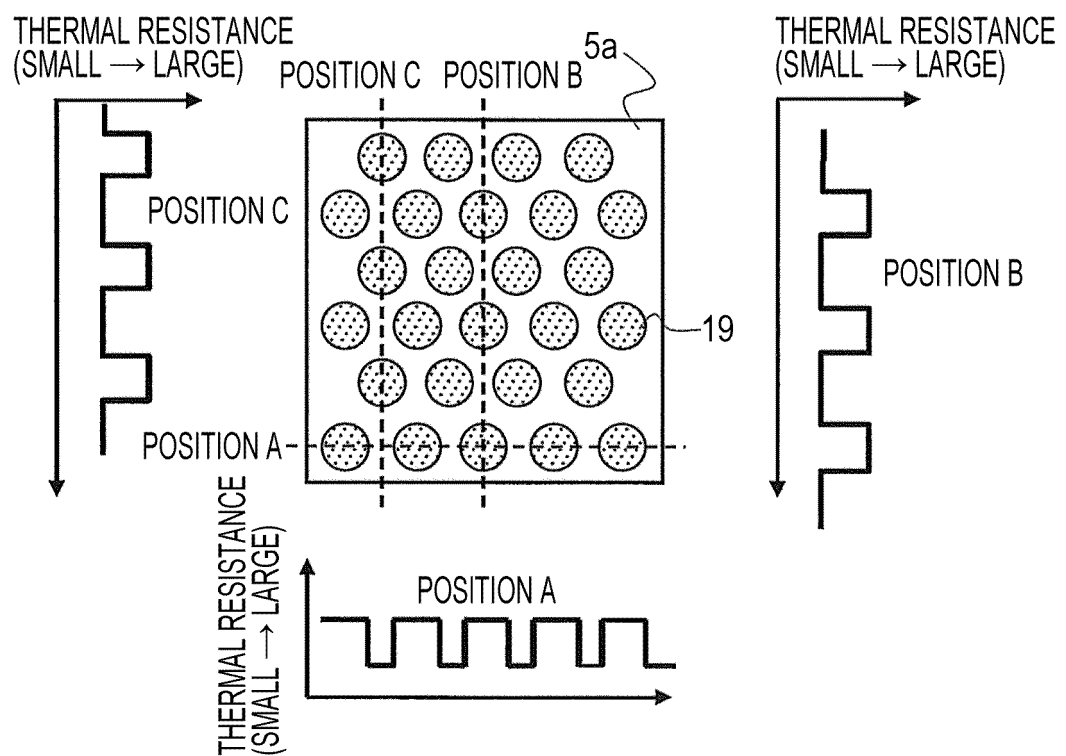


FIG. 5

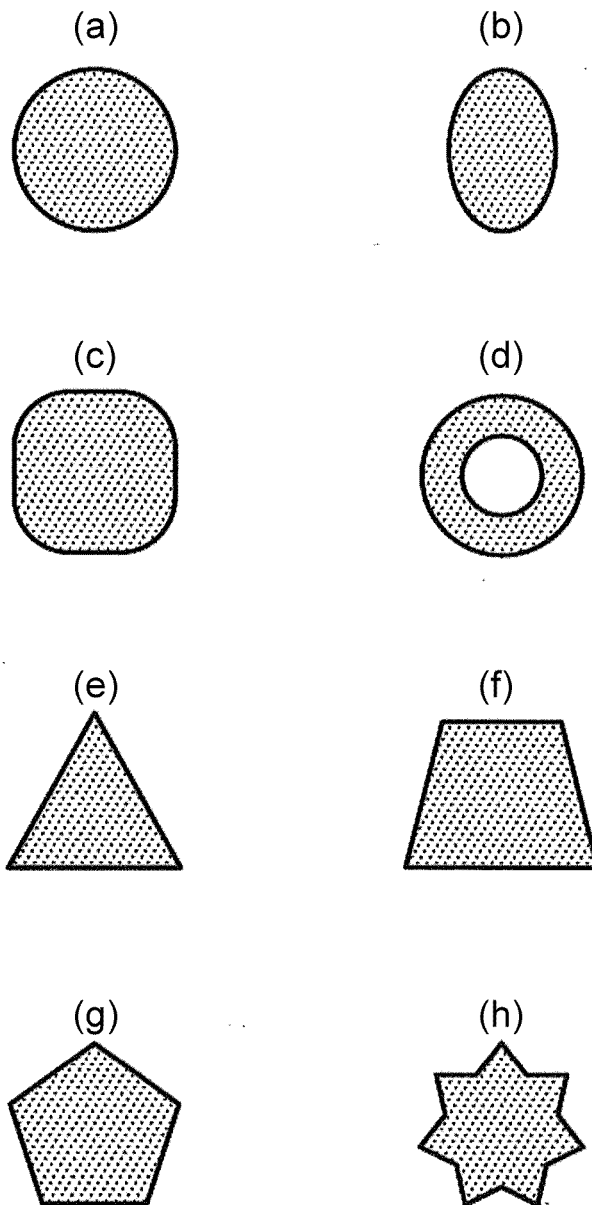


FIG. 6

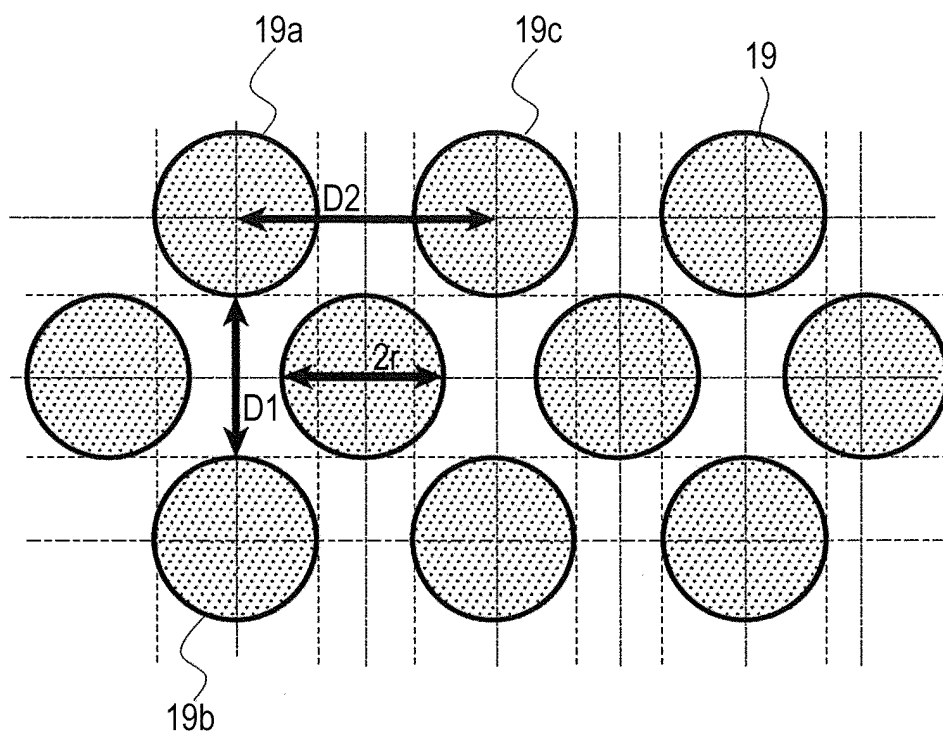


FIG. 7

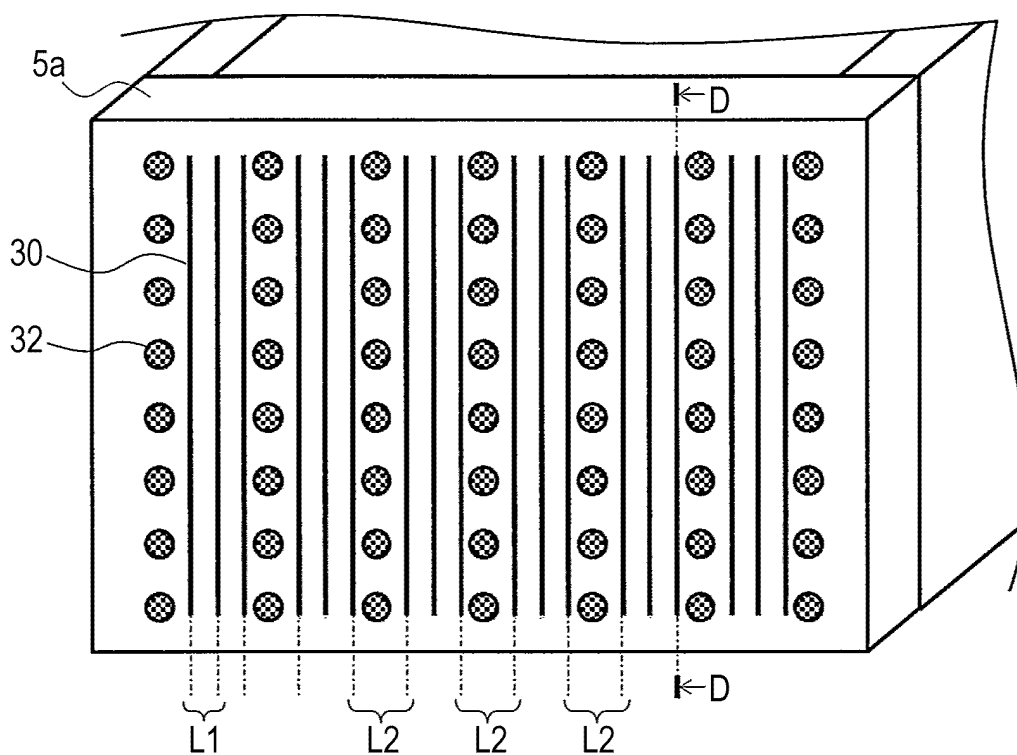


FIG. 8

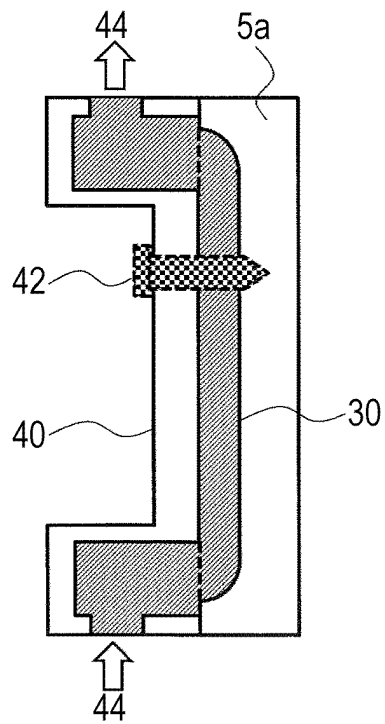
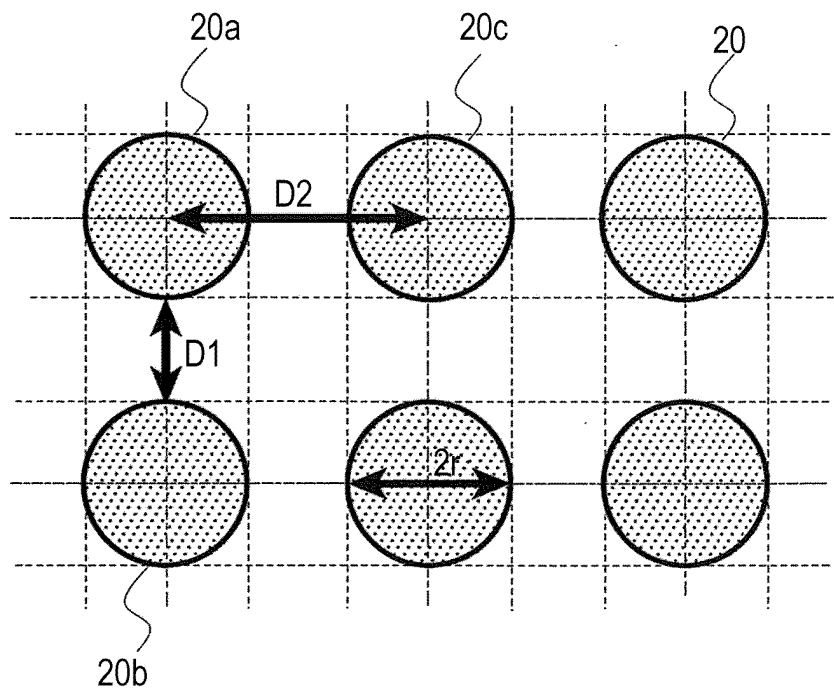


FIG. 9



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2017/033955

A. CLASSIFICATION OF SUBJECT MATTER

B22D11/04(2006.01)i, B22D11/059(2006.01)i, B22D11/128(2006.01)i,
B22D11/16(2006.01)i, B22D11/20(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B22D11/00-B22D11/22

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

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2017
Kokai Jitsuyo Shinan Koho 1971-2017 Toroku Jitsuyo Shinan Koho 1994-2017

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 2015-96277 A (JFE Steel Corp.), 21 May 2015 (21.05.2015), paragraphs [0050] to [0063]; fig. 1 to 2 (Family: none)	1-8
Y	WO 2014/002409 A1 (JFE Steel Corp.), 03 January 2014 (03.01.2014), paragraphs [0017] to [0081]; fig. 1 to 3 & US 2015/0258603 A1 paragraphs [0042] to [0103]; fig. 1 to 3 & JP 2015-6695 A & EP 2839901 A1 & KR 10-2015-0009985 A & CN 104395015 A & TW 201408397 A	1, 3-8

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

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Date of the actual completion of the international search
08 November 2017 (08.11.17)

Date of mailing of the international search report
21 November 2017 (21.11.17)

Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2017/033955

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2016/067578 A1 (JFE Steel Corp.), 06 May 2016 (06.05.2016), paragraphs [0035] to [0069]; fig. 1 to 12 & EP 3213838 A1 paragraphs [0035] to [0069]; fig. 1 to 12 & KR 10-2017-0057406 A & CN 107148322 A & TW 201615303 A	1-8
Y	JP 2014-188521 A (JFE Steel Corp.), 06 October 2014 (06.10.2014), paragraphs [0049] to [0051]; fig. 1 (Family: none)	5-8
Y	WO 2014/020860 A1 (JFE Steel Corp.), 06 February 2014 (06.02.2014), paragraphs [0024] to [0045]; fig. 1 & EP 2881196 A1 paragraphs [0024] to [0045]; fig. 1 & CN 104507598 A & KR 10-2015-0023796 A	7-8
Y	JP 57-206555 A (Kawasaki Steel Corp.), 17 December 1982 (17.12.1982), page 3, lower right column, line 9 to page 5, upper right column, line 4; fig. 5 to 6 (Family: none)	8

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REFERENCES CITED IN THE DESCRIPTION

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- JP 7210382 A [0014]
- JP 9206903 A [0014]
- JP 11099285 A [0014]

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- **P. PERMINOV et al.** *Steel in English*, 1968, 560-562 [0015]