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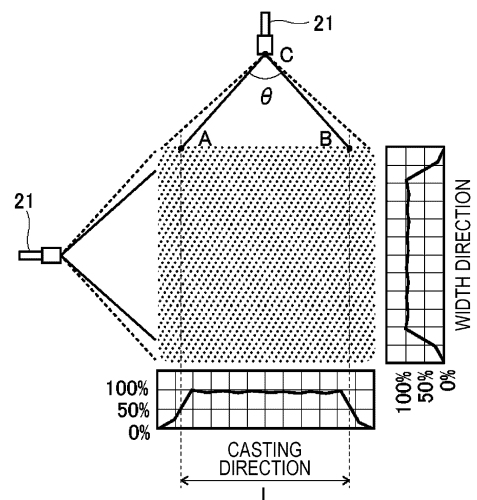
(54) **SECONDARY COOLING METHOD FOR CONTINUOUS CAST SLAB**

(57) Provided is a secondary cooling method for a continuously cast strand that allows the facility to be maintained easily and allows the uniformity of the cooling capacity to be improved.

The secondary cooling method for a continuously cast strand according to the present invention includes cooling a strand 5 using spray nozzles 21 having a quadrangular spray pattern. The spray nozzles 21 are arranged in the width direction of the strand between guide rolls 19 having a radius d (unit: mm) and arranged in a casting direction with a center-to-center distance P (unit: mm) in part or all of a horizontal zone 15 in a secondary cooling zone of a continuous casting machine 1. For each of the spray nozzles 21 that spray cooling water, values of the water volume density of the cooling water at two points A and B that are spaced apart in the casting direction by a distance L (unit: mm) are 50% of the maximum value of the water volume density in the casting direction, and the relation between the distance L and the center-to-center distance P satisfies formula (1) below. The strand is cooled while a nucleate boiling state is maintained in the range between the point A and the point B:

$$L/P \geq 0.70. \quad (1)$$

FIG. 1



Description

Technical Field

5 **[0001]** The present invention relates to a secondary cooling method for a continuously cast strand.

Background Art

10 **[0002]** A general method for producing a continuously cast strand will be described with reference to Figs. 4 and 5 using a vertical bending continuous casting facility as an example.

[0003] Molten steel poured from a tundish (not shown) into a mold 3 is subjected to primary cooling in the mold 3 to form a flat plate-shaped strand 5 having a solidifying shell. The strand 5 travels downward through a vertical zone 7 keeping the flat plate-shape to a curved zone 11. The strand 5 is bent in a bending unit 9 on the entrance side of the curved zone 11 while guided by a plurality of rolls (not shown) such that a constant radius of curvature is maintained.

15 **[0004]** Then the strand 5 is bent back (straightened) in a straightening unit 13 while the radius of curvature is gradually increased. The strand 5 exiting the straightening unit 13 has a flat plate shape again and travels to a horizontal zone 15. After completion of solidification in the horizontal zone 15, the strand 5 is cut to a prescribed length by a gas cutting machine 17 disposed on the exit side of the continuous casting machine 1.

20 **[0005]** After exiting the mold 3, the strand 5 is subjected to secondary cooling using water sprays (water-fluid sprays or water-air binary fluid mixture mist sprays) in a region extending from the vertical zone 7 to the horizontal zone 15 in order to complete solidification of a central portion of the strand 5.

[0006] Generally, during the secondary cooling, a large amount of water is sprayed in the vertical zone 7 immediately below the mold to perform intensive cooling to thereby ensure the strength of the shell. In the curved zone 11 and the subsequent thereof, the degree of cooling is rather reduced, and the surface temperature is increased by heat conduction from the high-temperature inner portion (recuperation). In the straightening unit 13, the surface temperature is adjusted to over the embrittlement temperature range to avoid the occurrence of transverse cracking.

25 **[0007]** For some types of steel, the speed of casting may be increased for the purpose of improving the production efficiency. In this method, the strand is straightened while the central portion of the strand is unsolidified, and the solidification is completed by performing intensive cooling in the horizontal zone 15 in the final stage of the continuous casting. When the cooling capacity in the intensive cooling zone is unstable, temperature variations occur on the surface of the strand, and surface cracking occurs due to thermal stress caused by the temperature variations. When intensive cooling is performed in the final stage of the continuous casting process, the solidification completion position in the central portion of the strand is unsteady due to any uneven cooling, and this affects the interior quality of the strand. Therefore, to achieve a high cooling capacity stably in the intensive cooling zone, it is desirable that the cooling water maintains a nucleate boiling state on the surface of the strand.

30 **[0008]** In the secondary cooling zone, a plurality of guide rolls 19 are disposed, and the cooling water is sprayed between the guide rolls 19 (see Fig. 5).

[0009] When the spray state of the cooling water from spray nozzles 21 (an example in the horizontal zone 15) is observed from a short-side side of the strand, there are directly sprayed regions X in which the cooling water is directly sprayed onto the surface of the strand and non-directly sprayed regions Y in which the cooling water is blocked by the guide rolls 19 and contact portions between the strand 5 and the guide rolls 19 and does not impinge on the strand 5 directly, as shown in Fig. 5.

35 **[0010]** In the directly sprayed regions X, the high cooling capacity is maintained because the cooling water is continuously supplied from the nozzles. However, in the non-directly sprayed regions Y, heat is removed only by contact with the guide rolls 19 and retained water, so that the cooling capacity is low. Therefore, when the strand travels from a directly sprayed region X to a non-directly sprayed region Y, the surface temperature of the strand increases greatly (recuperation). In this case, even when the strand enters a next directly sprayed region X between rolls, the nucleate boiling state is not obtained rapidly, and the boiling state varies unstably in the casting direction, so that large temperature fluctuations occur. A similar unstable transition of the boiling state can occur also in the width direction of the strand, so that a large temperature difference occurs also in the width direction of the strand. These temperature fluctuations cause thermal stress to be generated on the surface of the strand, and surface cracking thereby occurs. Moreover, the solidification completion position becomes unsteady in the width direction of the strand. In this case, the internal quality deteriorates, and this results in problems in quality.

40 **[0011]** As a method for increasing the uniformity of the local cooling capacity during the secondary cooling in the continuous casting process described above, for example, Patent Literature 1 proposes a technique for increasing the uniformity of the cooling capacity by specifying the ratio of the length of regions directly sprayed with water in the casting direction to the distance between guide rolls.

55 **[0012]** Patent Literature 2 proposes a technique in which coolant guide plates are disposed between guide rolls so as

to be close to the surface of the strand in order to spread the cooling water over the surface of the strand.

Citation List

5 Patent Literature

[0013]

PTL 1: Japanese Unexamined Patent Application Publication No. 2003-136205

10 PTL 2: Japanese Unexamined Patent Application Publication No. 2018-15781

Summary of Invention

Technical Problem

15 **[0014]** With the technique in Patent Literature 1, the uniformity of cooling in the casting direction is improved by increasing the area of the regions sprayed directly with water. However, no mention is made of the boiling state in the directly sprayed regions, and it is unclear whether nucleate boiling is achieved and maintained stably under the intensive cooling conditions described above.

20 **[0015]** Although the spray pattern of the spray water used in the width direction of the strand is not described, it can be inferred that the water is sprayed as two elliptical streams. In this case, the spray width and the water volume density of the spray water at the edges in the width direction are smaller than those at the center, so that the intended uniformity of the cooling capacity cannot be achieved. It is stated that it is preferable that the spray nozzles each have a plurality of spray ports. However, in this case, the shape of the nozzles is complicated, and the risk of nozzle clogging increases,

25 **[0016]** In the technique in Patent Literature 2, the coolant guide plates are disposed near the surface of the strand to form a water film flowing at high speed between the strand and the guide plates, and it is stated that this allows non-boiling and nucleate boiling states to be achieved.

30 **[0017]** However, since the guide plates are disposed very close to the surface of the strand, the risk of collision is high, and there may be a possibility that flaws are formed on the surface of the strand and the guide plates are damaged.

[0018] Moreover, small-diameter water supply ports are disposed near the strand. Therefore, even when no collision or damage occurs, the water supply ports may be clogged with scale pieces during continuous use. The damage to the guide plates or clogging of the water supply ports may cause the water film formed to be non-uniform. In this case, the nucleate boiling state cannot be achieved, and this causes non-uniformity of cooling. Therefore, to obtain uniformity of

35 the cooling capacity, it is important to maintain the soundness of the facility. However, since the guide plates are disposed so as to block the spaces between the rolls, they cannot be easily detached and attached for inspection. Therefore, to perform the uniform cooling claimed, a high facility management cost is required.

[0019] As described above, the spray conditions of water sprays that allow the nucleate boiling state to be achieved and maintained in both the casting direction and the strand width direction have not been found.

40 **[0020]** The present invention has been made to solve the foregoing problems, and it is an object to provide a secondary cooling method for a continuously cast strand in which the nucleate boiling state can be achieved stably in both the casting direction of the strand and the width direction thereof, so that the facility can be easily maintained and the uniformity of the cooling capacity can be improved.

45 Solution to Problem

[0021] To solve the foregoing problems, the present invention has the following features.

50 [1] A secondary cooling method for a continuously cast strand, the secondary cooling method including cooling a strand using spray nozzles having a quadrangular spray pattern, the spray nozzles being arranged in a width direction of the strand between guide rolls having a radius d (unit: mm), the guide rolls being arranged in a casting direction with a center-to-center distance P (unit: mm) in part or all of a horizontal zone in a secondary cooling zone of a continuous casting machine,

55 wherein, for each of the spray nozzles that spray cooling water, values of a water volume density of the cooling water at two points A and B that are spaced apart in the casting direction by a distance L (unit: mm) are 50% of a maximum value of the water volume density in the casting direction, wherein the relation between the distance L and the center-to-center distance P satisfies formula (1) below, and

wherein the strand is cooled while a nucleate boiling state is maintained in a range between the point A and the point B:

$$L/P \geq 0.70. \quad (1)$$

[2] The secondary cooling method for a continuously cast strand according to [1], wherein an angle θ (unit: degrees) between a straight line connecting a nozzle spray port of the each of the spray nozzles to the point A and a straight line connecting the nozzle spray port to the point B satisfies formula (2) below, and wherein a nozzle height h (unit: mm) of the nozzle spray port from the strand satisfies formula (3) below:

$$180 - 4\tan^{-1}[3P/(20d)] \leq \theta \leq 100, \quad (2)$$

$$7P/[20\tan(\theta/2)] \leq h \leq [P - 2d\tan\{(180 - \theta)/4\}]/[2\tan(\theta/2)]. \quad (3)$$

[3] The secondary cooling method for a continuously cast strand according to [1] or [2], wherein the water volume density of the cooling water sprayed from each of the spray nozzles per unit surface area of the strand in a cooling section cooled using the spray nozzles is from 400 (L/m²)/min to 2000 (L/m²)/min inclusive.

Advantageous Effects of Invention

[0022] In the present invention, the spray nozzles having a quadrangular spray pattern are arranged in the width direction of the strand in the secondary cooling zone of the continuous casting machine. For each of the spray nozzles that spray the cooling water, the values of the water volume density of the cooling water at the two points A and B that are spaced apart in the casting direction by a distance L (unit: mm) are 50% of the maximum value in the water volume distribution in the casting direction. The guide rolls and the spray nozzles are disposed such that the relation between the distance L and the center-to-center distance P satisfies $L/P \geq 0.70$. The strand is cooled while the nucleate boiling state is maintained in the range between the points A and B, and this allows the nucleate boiling to be achieved and maintained stably over a wide area of the surface of the strand, so that a high-quality strand can be produced stably.

Brief Description of Drawings

[0023]

[Fig. 1] Fig. 1 is an illustration showing a spray pattern of spray nozzles and flow distributions in an embodiment of the present invention.

[Fig. 2] Fig. 2 is an illustration showing the arrangement relation between a spray nozzle and guide rolls in the embodiment of the present invention.

[Fig. 3] Fig. 3 is an illustration showing the spray pattern of spray nozzles and flow distributions in Comparative Example 1 in the description of Examples.

[Fig. 4] Fig. 4 is an illustration showing the outline of a conventional general continuous casting facility.

[Fig. 5] Fig. 5 is an illustration showing the arrangement of guide rolls and spray nozzles in the conventional general continuous casting facility and a spray state.

Description of Embodiments

[0024] A secondary cooling method for a continuously cast strand in an embodiment is used in a continuous casting machine 1 having a secondary cooling zone including a vertical zone 7, a bending unit 9, a curved zone 11, a straightening unit 13, and a horizontal zone 15 that are disposed in this order from the upstream side in a casting direction (see Fig. 4). The secondary cooling method includes cooling a strand 5 using spray nozzles 21 having a quadrangular spray pattern. The spray nozzles 21 are arranged in the width direction of the strand between guide rolls 19 having a radius d (unit: mm) in part or all of the horizontal zone 15 in the secondary cooling zone. The guide rolls 19 are arranged in the

casting direction with a center-to-center distance P (unit: mm). For each of the spray nozzles 21 that spray cooling water, the values of the water volume density of the cooling water at two points A and B that are spaced apart in the casting direction by a distance L (unit: mm) are 50% of the maximum value in the water volume distribution in the casting direction. The guide rolls 19 and the spray nozzles 21 are disposed such that the relation between the distance L and the center-to-center distance P satisfies formula (1) below, and the strand 5 is cooled while a nucleate boiling state is maintained in the range between the point A and the point B.

$$L/P \geq 0.70 \quad (1)$$

[0025] In the present embodiment, the spray nozzles 21 used have a quadrangular spray pattern as shown in Fig. 1. The reason that the spray nozzles 21 having the quadrangular spray pattern are used is as follows.

[0026] When the surface of the strand is cooled by using the spray nozzles 21 disposed between the guide rolls 19, an exposed portion of the surface of the strand (the surface to be cooled) has an elongated rectangular shape (long in the width direction of the strand and short in the casting direction). To spray the cooling water uniformly over the elongated rectangular area as wide as possible, it is preferable to arrange the spray nozzles 21 having the quadrangular spray pattern in the width direction of the strand. In this manner, the cooling water can be sprayed directly onto the surface to be cooled uniformly without unsprayed areas, and nucleate boiling occurs uniformly, so that no local recuperation occurs.

[0027] Widthwise water volume density distributions of spray nozzles 21 adjacent in the width direction of the strand overlap each other to form a lapping portion. It is desirable that lapping margins of the spray regions of the adjacent spray nozzles 21 are set such that the water volume density in the lapping portion is from 50% to 100% of the maximum value of the water volume density when the water is sprayed from one spray nozzle.

[0028] If the water volume density in the lapping portion is less than 50% of the maximum value, the water volume density in the lapping portion is insufficient, and the nucleate boiling state is not obtained during cooling, so that temperature unevenness occurs in the width direction. If the water volume density in the lapping portion is more than 100%, the lapping region is too large. In this case, streams of the cooling water from adjacent spray nozzles 21 interfere so much with each other, and the expected water volume density distribution is not obtained when the cooling water is actually sprayed, so that it is highly feared that cooling may be nonuniform.

[0029] Moreover, in the present embodiment, for each of the spray nozzles 21 that spray the cooling water, the values of the water volume density of the cooling water at the two points A and B that are spaced apart in the casting direction by a distance L (unit: mm) are 50% of the maximum value in the water volume distribution in the casting direction. The guide rolls 19 and the spray nozzles 21 are disposed such that the relation between the distance L and the center-to-center distance P satisfies $L/P \geq 0.70$.

[0030] The reason for the above arrangement is as follows.

[0031] When intensive cooling is performed by utilizing nucleate boiling, the difference between the cooling capacity in the portions directly sprayed with the cooling water from the spray nozzles 21 and the cooling capacity in non-directly sprayed portions is so large. Therefore, the difference between the temperature in the directly sprayed portions and the temperature in the non-directly sprayed portions is large, and this causes defects such as cracking. Moreover, if recuperation in the non-directly sprayed portions is excessively large when the flow rate of the cooling water is reduced, nucleate boiling does not occur also in the directly sprayed portions, and this may cause temperature unevenness.

[0032] However, when $L/P \geq 0.70$, the area of the non-directly sprayed portions are narrow, and the volume of the cooling water flowing from the directly sprayed portions to the non-directly sprayed portions is large enough not to prevent cooling of the strand, so that temperature unevenness does not occur.

[0033] The cooling water impinging on the strand flows from the directly sprayed portions so as to spread outward. In this case, the flow in the casting direction is dammed in the gaps between the strand and the guide rolls. Then flows in the width directions of the strand are formed, and the cooling water is drained. Therefore, when the water volume density is large, if the area of the non-directly sprayed portions is excessively small, the flows near the rolls and the directly sprayed portions may interfere with each other. It is therefore desirable that the relation between the distance L between the two points A and B and the center-to-center distance P satisfies $L/P \leq 0.90$.

[0034] Since the spray pattern of the spray nozzles 21 in the present embodiment is quadrangular, the thickness of the sprays does not change in the width direction of the strand, and the L/P can fall within the specified range in the entire region in the width direction.

[0035] However, when the spray pattern is elliptical as in the spray nozzles in Patent Literature 1, the spray thickness in the directly sprayed portions is small at edge portions in the width direction of the strand, so that it is difficult to allow the value of L/P to fall within the prescribed range over the entire region in the width direction of the strand.

[0036] In the present embodiment, it is required to achieve and maintain the nucleate boiling state in order to perform intensive cooling stably.

[0037] To achieve and maintain the nucleate boiling state, not only the length of the portions directly sprayed with the cooling water but also the water volume density is an important factor. If the water volume density is insufficient, even when the strand 5 enters a range directly sprayed with the cooling water, the nucleate boiling state is not achieved immediately. In this case, the temperature of the strand 5 is reduced by film boiling, and then transition to nucleate boiling occurs.

[0038] In this case, the cooling rates differ at different widthwise positions (the widthwise central portion of the strand and the corners of the strand). Since the transition point from film boiling to nucleate boiling is influenced by the surface quality, the starting points of nucleate boiling vary in the width direction of the strand. Therefore, large temperature variations occur in the width direction, and surface cracking due to thermal stress or variations in the internal solidification completion positions in the width direction occur. This may cause surface and internal defects.

[0039] Accordingly, the inventors have conducted studies on the water volume density that allows the nucleate boiling state to be rapidly achieved and maintained in the portions directly sprayed with the cooling water and found that the water volume density must be at least 400 (L/m²)/min.

[0040] The reason that the water volume density must be at least 400 (L/m²)/min is as follows.

[0041] When the surface temperature of the strand is high, the cooling water on the surface of the strand is in the film boiling state, and a vapor film is formed. When the volume density of the sprayed water is less than 400 (L/m²)/min, the water volume density is small. In this case, the vapor film is not broken immediately by the impingement of the cooling water, and the film boiling state is maintained until the surface temperature of the strand is reduced to some extent. After then the surface temperature decreases, and the transition from film boiling to nucleate boiling occurs. Then the cooling proceeds rapidly.

[0042] Therefore, once variations in the surface temperature of the strand at different positions occur, the boiling states at different positions on the surface of the strand differ from each other, so that the temperature unevenness further increases.

[0043] However, when the water volume density is 400 (L/m²)/min or more, even if a vapor film is formed on the surface of the strand, the vapor film is broken immediately by the impingement of the cooling water, and the film boiling state is rapidly changed to the nucleate boiling state. Therefore, the boiling state is uniform irrespective of the position on the surface of the strand, and no temperature unevenness occurs.

[0044] When nucleate boiling occurs, cooling by the boiling is dominant, and therefore the dependence of the cooling capacity on the water volume density is small. Therefore, even when the water volume density is more than 2000 (L/m²)/min, it is not expected to largely improve the cooling capacity. In this case, the total amount of the cooling water used is excessively large, and the investment in the water processing facility increases. Therefore, it is suitable that the water volume density in the intensive cooling zone is in the range of from 400 (L/m²)/min to 2000 (L/m²)/min inclusive.

[0045] However, in the present invention, it is unnecessary to set the water volume density within the range of from 400 (L/m²)/min to 2000 (L/m²)/min inclusive under some operation conditions (such as the surface temperature of the strand, the impact pressure of the cooling water, etc.), and the water volume density may be set such that the nucleate boiling state is obtained.

[0046] For example, if the prescribed water volume density is not achieved for some reason such as a malfunction in the facility, e.g., water leakage from piping, and the nucleate boiling state is not achieved immediately after the strand enters the intensive cooling section, it is necessary to increase the water volume while the boiling state is monitored to thereby achieve and maintain the nucleate boiling state reliably.

[0047] When the cooling water comes into contact with the surface of the strand and is brought to a boil, the cooling water is vaporized to form water vapor. In this case, steam (a cloud of spray) formed by condensation of the water vapor in air is observed. In the nucleate boiling state, the cooling water in contact with the surface of the strand effervesces vigorously, and a large amount of water vapor is generated, so that the amount of the cloud of spray generated increases. However, in the film boiling state, the degree of effervescence of the boiling cooling water is small, and therefore the amount of water vapor and the amount of the cloud of spray are also small.

[0048] Therefore, a camera is installed in each section, and the amount of the cloud of spray generated is monitored by visual observation or measurement using a transmissometer. Specifically, the threshold of the amount of the cloud of spray generated at which film boiling changes to nucleate boiling is determined by experiments in advance. Then whether or not the amount of the cloud of spray generated exceeds the threshold is checked to determine whether the nucleate boiling state is achieved in a prescribed section. When the nucleate boiling state is not achieved, the volume of the cooling water is increased. In this manner, the nucleate boiling state can be achieved and maintained reliably.

[0049] In convective heat transfer including boiling, the fluid temperature and the solid temperature are locally equal to each other at the point of contact. The temperature of water in the liquid state can rise only to its boiling point under atmospheric pressure. Therefore, when nucleate boiling is achieved, the surface temperature of the strand is considered to be about 100°C. Thus, by measuring the temperature of the surface of the strand and the temperature of the cooling water therearound using contact-type thermometers each having a small probe to check whether the temperatures are stable at around 100°C, it is possible to check whether the nucleate boiling state is achieved. When the nucleate boiling

state is not achieved, the amount of the cooling water is increased. In this manner, the nucleate boiling state can be achieved and maintained reliably.

[0050] As described above, in the present embodiment, sprays of water having a quadrangular spray pattern are used in the region in which intensive cooling is performed in the secondary cooling zone, and the spray angle and the spray height are set such that the length of the portions directly sprayed with the cooling water between the guide rolls 19 is 70% of the spacing between the adjacent rolls. Then the cooling is performed while the nucleate boiling state is maintained in the portions directly sprayed with the cooling water. In this case, large temperature fluctuations on the surface of the strand can be prevented. Therefore, surface and internal defects such as surface cracking and variations in the solidification completion positions can be prevented, and a high-quality strand 5 can be produced stably.

[0051] The effects of the present embodiment will be demonstrated in Examples described later.

[0052] As shown in Fig. 2, the center of the nozzle spray port is denoted as point C. Then the angle (spray angle) θ (unit: degrees) between straight line CA and straight line CB is desirably set to 100 degrees or less in order to maintain the uniformity of the water volume distribution.

[0053] Two points at which the volume of the cooling water sprayed from the spray nozzle 21 is 50% of the maximum value in the water volume distribution in the casting direction are denoted as points A and B. Then it is necessary that the spray angle θ be set such that the distance L between the points A and B (hereinafter referred to as a directly sprayed portion length L) satisfies formula (1). The conditions that must be satisfied by the spray angle θ will be described.

[0054] As shown in Fig. 2, the length of $P/2 - L/2 = Y$ (referred to as a non-directly sprayed portion) satisfies the relation of formula (4) below.

[0055] Moreover, it is necessary that the spray angle θ be set within such a range that the straight lines CA and CB are not in contact with the guide rolls 19. Therefore, when the straight line CA (or the straight line CB) is in external contact with one of the guide rolls 19, formula (5) below holds for triangle DAE.

[0056] Preferably, based on these relations, the spray angle θ is set within the range of formula (2).

[Math. 1]

$$\frac{P}{2} - \frac{L}{2} \leq \frac{0.3}{2} P \quad \cdot \cdot \cdot (4)$$

$$\frac{P/2 - L/2}{d} = \tan\left(\frac{180 - \theta}{4}\right) \quad \cdot \cdot \cdot (5)$$

$$180 - 4 \tan^{-1} \frac{3P}{20d} \leq \theta \leq 100 \quad \cdot \cdot \cdot (2)$$

[0057] When the spray angle θ is determined so as to satisfy formula (2), the height h (unit: mm) from the surface of the strand is similarly determined. This will next be described.

[0058] The directly sprayed portion length L for a given spray angle θ can be expressed by formula (6). By substituting formula (6) into formula (1), the lower limit of the height h can be expressed by formula (7).

[0059] The upper limit of the height h is the position at which the straight lines CA and CB are in contact with the guide rolls 19, and therefore formula (8) holds. By substituting formula (6) into formula (8) and transforming the resulting formula with respect to the height h, the upper limit of the height h is expressed by formula (9). Therefore, the range of the height h is expressed by formula (3).

[Math. 2]

$$L = 2h \tan(\theta/2) \quad \cdot \cdot \cdot (6)$$

$$h \geq \frac{7P}{20 \tan(\theta/2)} \quad \cdot \cdot \cdot (7)$$

$$\frac{P}{2} - \frac{L}{2} = d \tan\left(\frac{180 - \theta}{4}\right) \quad \cdot \cdot \cdot (8)$$

$$h \leq \frac{P - 2d \tan[(180 - \theta)/4]}{2 \tan(\theta/2)} \quad \cdot \cdot \cdot (9)$$

$$\frac{7P}{20 \tan(\theta/2)} \leq h \leq \frac{P - 2d \tan[(180 - \theta)/4]}{2 \tan(\theta/2)} \quad \cdot \cdot \cdot (3)$$

[0060] By setting the spray angle θ of the spray nozzles 21 and the spray height h such that formulas (2) and (3) above are satisfied, the directly sprayed portion length L is 70% or more of the spacing P between the guide rolls. In this case, the range of the directly sprayed portions can be sufficiently large, and local fluctuations in the surface temperature of the strand can be prevented.

EXAMPLES

[0061] To examine the effects of the present invention, the secondary cooling method was performed. The details will next be described.

[0062] To perform intensive cooling in the horizontal zone 15 in the secondary cooling zone of the vertical bending continuous casting machine 1 (see Fig. 4), a strand 5 was produced using the cooling device (see Figs. 1 and 2) in the embodiment of the present invention.

[0063] The machine length of the continuous casting machine 1 is 45 m, and thermometers for measuring the temperature distribution on the surface of the strand and a gas cutting machine 17 are disposed at a machine end. Slabs were produced using guide rolls 19 with various radii, various spacings between the guide rolls 19, spray nozzles 21 with various spray angles, various pitches of the spray nozzles in the strand width direction, various installation heights of the spray nozzles, various casting speeds, and various water volume densities. Then temperature unevenness during cooling, the surface quality of the cast slabs, internal defects, and the cost of production were evaluated.

[0064] For the evaluation purposes, the thicknesses of all the cast slabs were set to 235 mm.

[0065] The casting conditions and the results are shown in Table 1.

[Table 1]

	Roll radius d [mm]	Roll spacing P [mm]	Spray pattern	Spray angle θ [°]	Nozzle height h [mm]	Length of directly sprayed portion L [mm]	Width pitch [mm]	Water volume ratio in lapping portion [%]	L/P [-]	Water volume density [(L/m ²) /min]	Casting speed [mpm]	Defects	Remarks
Comparative Example 1	100	300	Elliptical	30	100	64	250	70	0.21	100	1.5	Surface cracks and internal defects	
Comparative Example 2	100	300	Quadrangular	70	139	195	250	50	0.65	400	3.0	Surface cracks	L is insufficient
Comparative Example 3	100	300	Quadrangular	95	90	196	250	60	0.66	400	3.0	Surface cracks	h is outside lower limit
Comparative Example 4	100	300	Quadrangular	95	105	(217)	260	70	(0.72)	(380)	3.0	Surface cracks and internal defects	h is outside upper limit
Comparative Example 5	100	300	Quadrangular	95	99	216	250	80	0.72	350	2.8	Surface cracks and internal defects	Water volume is insufficient
Comparative Example 6	80	250	Quadrangular	95	99	(178)	250	80	(0.71)	(330)	3.0	Surface cracks and internal defects	d and P changed
Comparative Example 7	100	300	Quadrangular	95	99	216	275	40	0.72	400	3.0	Longitudinal cracks	Width pitch is unsuitable
Example 1	100	300	Quadrangular	95	99	216	250	80	0.72	400	3.0	-	
Example 2	100	300	Quadrangular	95	99	216	250	80	0.72	2000	3.0	-	
Example 3	100	300	Quadrangular	84	117	210	250	70	0.70	400	3.0	-	Lower limit of θ

(continued)

	Roll radius d [mm]	Roll spacing P [mm]	Spray pattern	Spray angle θ [°]	Nozzle height h [mm]	Length of directly sprayed portion L [mm]	Width pitch [mm]	Water volume ratio in lapping portion [%]	L/P [-]	Water volume density [(L/m ²)/min]	Casting speed [mpm]	Defects	Remarks
Example 4	100	300	Quadrangular	100	92	219	250	85	0.73	400	3.0	-	Upper limit of θ
Example 5	100	300	Quadrangular	95	97	210	250	75	0.70	400	3.0	-	Lower limit of h
Example 6	100	300	Quadrangular	95	101	222	250	90	0.74	400	3.0	-	Upper limit of h
Example 7	80	250	Quadrangular	95	85	185	210	90	0.74	400	3.0	-	d and P changed

[0066] In Comparative Example 1 and Examples 1 and 2, slabs were cast using the conditions of a conventional technique and the technique of the present invention, respectively. In Comparative Example 1, water sprays having an elliptic spray pattern (see Fig. 3) were used. The spray angle of the sprays in the casting direction was small, i.e., 30° , and $L/P = 0.21$. Therefore, temperature fluctuations in the portions directly sprayed with the cooling water and the non-directly sprayed portions were large. The produced slab was inspected, and surface cracking due to the temperature fluctuations was found on the surface of the slab.

[0067] Since the water volume density was as small as $100 \text{ (L/m}^2\text{)/min}$, the nucleate boiling state could not be achieved rapidly over the entire width of the strand. Therefore, the strand could not be cooled efficiently, and the casting speed was limited to 1.5 m/s . Moreover, the solidification completion position in the central inner portion of the strand was unsteady, and the deviation of centerline segregation and internal defects such as internal cracking were found.

[0068] In Example 1, the technique of the present invention was applied. Specifically, water sprays having a quadrangular spray pattern were used, and the relation between the spray angle and the nozzle installation height was set appropriately to obtain $L/P = 0.72$. The water volume density was set to $400 \text{ (L/m}^2\text{)/min}$, and the casting speed was increased to 3.0 m/s .

[0069] Therefore, the temperature fluctuations in the casting direction could be reduced, and the boiling state could be achieved rapidly and maintained in the width direction of the strand. The cast slab was inspected. Then no surface defects and no internal defects were found, and the high quality slab could be produced highly efficiently.

[0070] In Example 2, the same facility arrangement as that in Example 1 was used, and the water volume density of the cooling water was set to $2000 \text{ (L/m}^2\text{)/min}$. In this case, the temperature fluctuations in the casting direction could be reduced, and the boiling state could be achieved rapidly and maintained in the width direction of the strand. The cast slab was inspected. Then no surface defects and no internal defects were found, and the high quality slab could be produced highly efficiently.

[0071] In Comparative Example 2 and Examples 3 and 4, water sprays having a quadrangular spray pattern were used, and the water volume density was set to $400 \text{ (L/m}^2\text{)/min}$. Therefore, in all the Examples, the nucleate boiling state could be achieved rapidly at the entrance of the intensive cooling zone and maintained in the portions directly sprayed with the cooling water.

[0072] However, in Comparative Example 2, the spray angle θ was 70° , and $L/P = 0.65$. Therefore, fluctuations of the temperature in between the portions directly sprayed with the cooling water and the non-directly sprayed portions were large. The cast slab was checked, and surface cracking was found.

[0073] In Example 3, the nozzles used had a smaller spray angle (84°) than that in Example 1. However, the nozzle height was adjusted to achieve $L/P = 0.70$, and the temperature fluctuations in the casting direction could be reduced. The cast slab was inspected. Then no surface defects and no internal defects were found, and the high quality slab could be produced highly efficiently.

[0074] In Example 4, the nozzles used had a larger spray angle (100°) than that in Example 1. The nozzle height was adjusted to achieve $L/P = 0.73$, and the temperature fluctuations in the casting direction could be reduced. The cast slab was inspected. Then no surface defects and no internal defects were found, and the high quality slab could be produced highly efficiently, as in Example 3.

[0075] In Comparative Examples 3 and 4 and Examples 5 and 6, the spray height was changed with respect to the condition in Example 1. When the spray angle of the nozzles used is 95° , the range of the spray height h determined from formula (3) is 97 to 101 mm . In Examples 5 and 6, the spray heights h were set to the lower and upper limits, respectively, and these conditions satisfy $L/P \geq 0.70$. The cast slabs were inspected. Then no surface defects and no internal defects were found, and the high quality slabs could be produced highly efficiently.

[0076] However, in Comparative Example 3, the spray height h was lower than the lower limit ($h = 90 \text{ mm}$), and L/P was 0.66 and was lower than 0.70 . Therefore, the temperature of the surface of the strand fluctuated largely. The cast slab was inspected, and surface cracking was found.

[0077] In Comparative Example 4, the spray height h ($h = 105 \text{ mm}$) was larger than the upper limit, and a part of the sprayed cooling water was blocked by the guide rolls 19. Another part of the cooling water passed between the guide rolls 19, and the directly sprayed portion length L satisfied $L/P = 0.72$, so that L/P was 0.70 or more. However, the water volume density was reduced to $380 \text{ (L/m}^2\text{)/min}$, so that the nucleate boiling state could not be achieved stably. The cast slab was inspected, and surface cracks and internal defects were found.

[0078] In Comparative Example 5, the same spray nozzles 21 as those in Example 1 were used, and the water volume density was reduced to $350 \text{ (L/m}^2\text{)/min}$. In this case, the nucleate boiling state could not be achieved stably, as in Comparative Example 4. The cast slab was inspected, and surface cracks and internal defects were found.

[0079] In Comparative Example 6 and Example 7, the same spray nozzles 21 as those in Example 1 were used, and the radius d of the guide rolls 19 and their spacing P were changed to 80 mm and 250 mm , respectively.

[0080] In Comparative Example 6, the nozzle height h was set to be the same as that in Example 1. Therefore, the nozzle height h was larger than the upper limit of the height h (86 mm) determined by the radius d and the separation distance P , and a part of the cooling water was blocked by the guide rolls 19. Another part of the cooling water passed

between the guide rolls 19, and the directly sprayed portion length L satisfied $L/P = 0.71$, so that L/P was 0.70 or more. However, the water volume density was reduced to 330 (L/m²)/min, so that the nucleate boiling state could not be achieved stably. The cast slab was inspected, and surface cracks and internal defects were found.

[0081] In Example 7, the nozzle installation height was adjusted to 85 mm to allow all the cooling water to be sprayed onto the strand. In this case, the water volume density was adjusted to the intended value, 400(L/m²)/min, and L/P was 0.74 and satisfied to be equal to or more than 0.70. Therefore, the temperature fluctuations on the surface of the strand could be reduced, and the nucleate boiling state could be achieved rapidly and maintained. The cast slab was inspected. Then no surface defects and no internal defects were found, and the high quality slab could be produced highly efficiently.

[0082] As described above, when the secondary cooling is performed with L/P set to be 0.70 or more under the conditions that allow the nucleate boiling state to be maintained, it was confirmed that a high-quality slab can be produced highly efficiently without causing surface and internal defects to be formed in the slab.

[0083] In Examples 1 to 6, the spray nozzles 21 were disposed between the support rollers in the secondary cooling zone and arranged on straight lines (no staggered arrangement) with a spacing of 250 mm (width pitch: 250 mm) so as to be parallel to the rolls. In Example 7, the spray nozzles 21 were arranged with a spacing of 210 mm. Under any of these conditions, the water volume density in the lapping portions was within the range of from 50% to 100% of the maximum value, and no defects were found as described above.

[0084] In Comparative Example 7, only the width pitch of the spray nozzles 21 in Example 1 was changed to 275 mm, and the water volume density in the lapping portions was 40% of the maximum value, so that the nucleate boiling state could not be achieved stably. In Comparative Example 7, temperature unevenness in the width direction was found along the arrangement of the spray nozzles 21 and was clearly noticeable even by visual inspection. Moreover, vertical cracking considered to be due to the temperature unevenness in the width direction was found on the surface of the slab.

[0085] As can be seen, it is preferable that the spray nozzles 21 are disposed such that the water volume density in the lapping portions is in the range of from 50% to 100% of the maximum value.

Reference Signs List

[0086]

1 continuous casting machine

3 mold

5 strand

7 vertical zone

9 bending unit

11 curved zone

13 straightening unit

15 horizontal zone

17 gas cutting machine

19 guide roll

21 spray nozzle

A, B points at which the volume of the cooling water sprayed from the spray nozzles is 50% of the maximum value in the water volume distribution in the casting direction

C nozzle spray port

θ angle between straight line AB and straight line BC

P center-to-center distance of guide rolls

d radius of a guide roll

Claims

1. A secondary cooling method for a continuously cast strand, the secondary cooling method comprising cooling a strand using spray nozzles having a quadrangular spray pattern, the spray nozzles being arranged in a width direction of the strand between guide rolls having a radius d (unit: mm), the guide rolls being arranged in a casting direction with a center-to-center distance P (unit: mm) in part or all of a horizontal zone in a secondary cooling zone of a continuous casting machine,

wherein, for each of the spray nozzles that spray cooling water, values of a water volume density of the cooling water at two points A and B that are spaced apart in the casting direction by a distance L (unit: mm) are 50% of a maximum value of the water volume density in the casting direction, wherein the relation between the

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distance L and the center-to-center distance P satisfies formula (1) below, and wherein the strand is cooled while a nucleate boiling state is maintained in a range between the point A and the point B:

$$L/P \geq 0.70. \quad (1)$$

2. The secondary cooling method for a continuously cast strand according to claim 1, wherein an angle θ (unit: degrees) between a straight line connecting a nozzle spray port of the each of the spray nozzles to the point A and a straight line connecting the nozzle spray port to the point B satisfies formula (2) below, and wherein a nozzle height h (unit: mm) of the nozzle spray port from the strand satisfies formula (3) below:

$$180 - 4\tan^{-1}[3P/(20d)] \leq \theta \leq 100, \quad (2)$$

$$7P/[20\tan(\theta/2)] \leq h \leq [P - 2d\tan\{(180 - \theta)/4\}]/[2\tan(\theta/2)]. \quad (3)$$

3. The secondary cooling method for a continuously cast strand according to claim 1 or 2, wherein the water volume density of the cooling water sprayed from each of the spray nozzles per unit surface area of the strand in a cooling section cooled using the spray nozzles is from 400 (L/m²)/min to 2000 (L/m²)/min inclusive.

FIG. 1

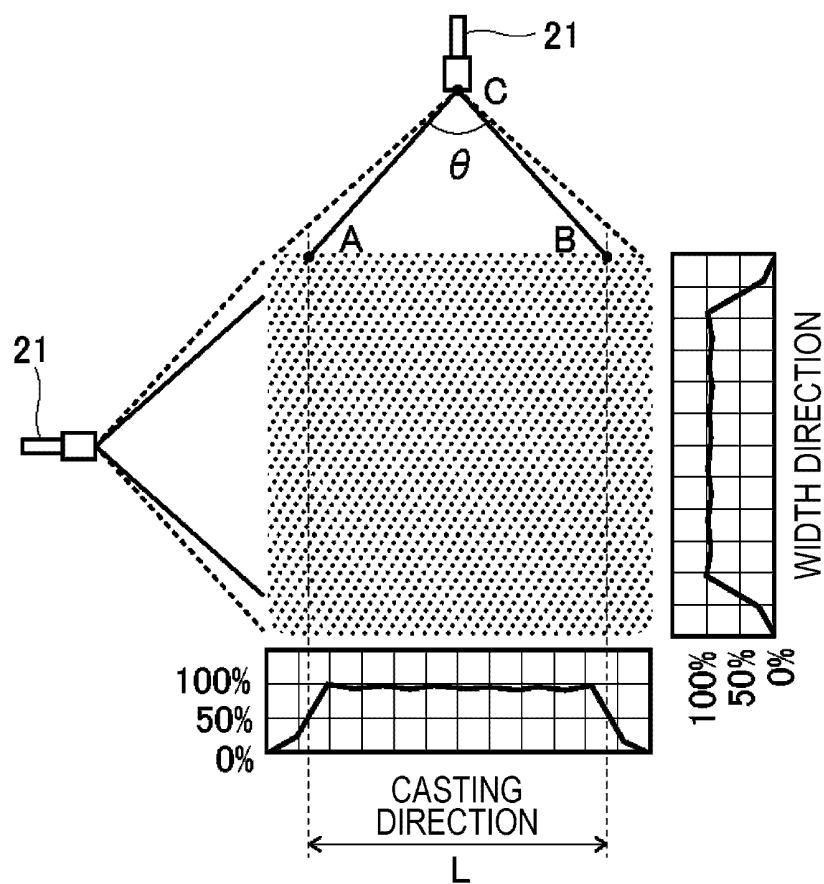


FIG. 2

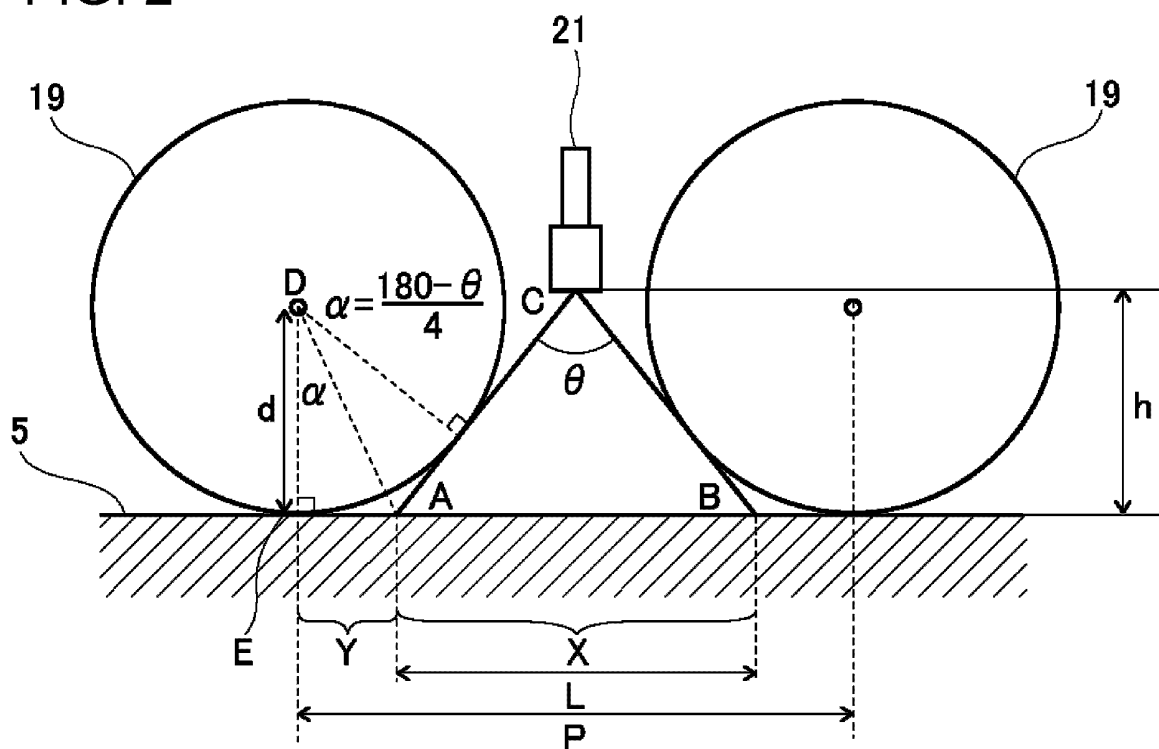


FIG. 3

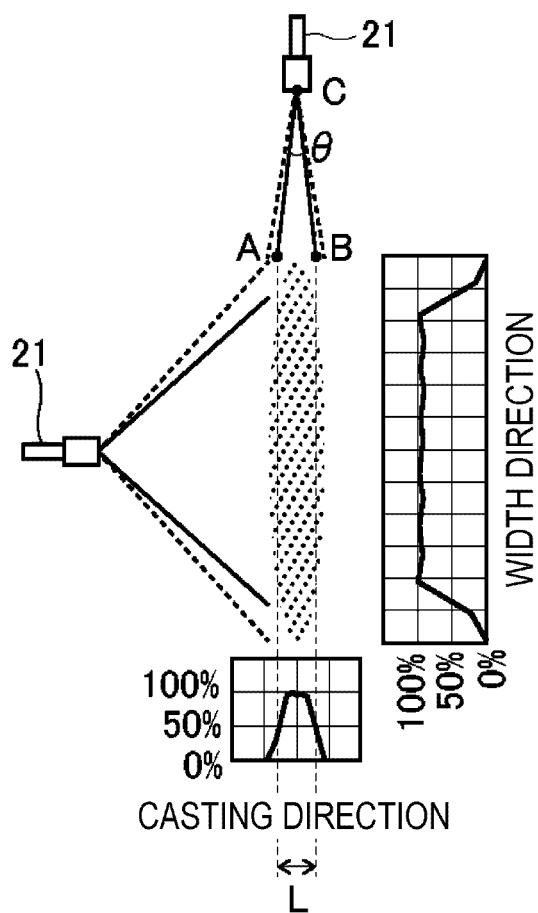


FIG. 4

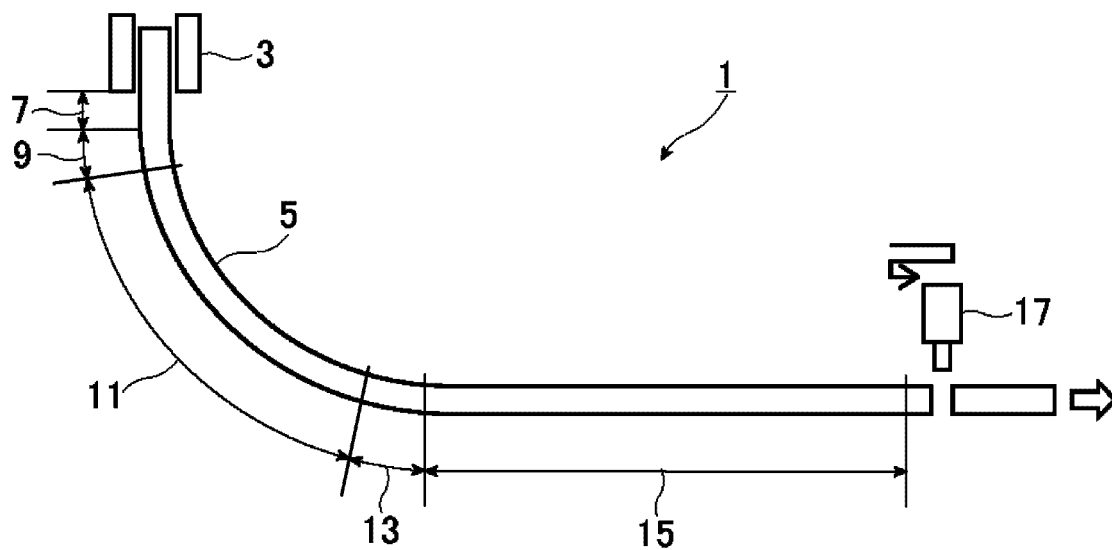
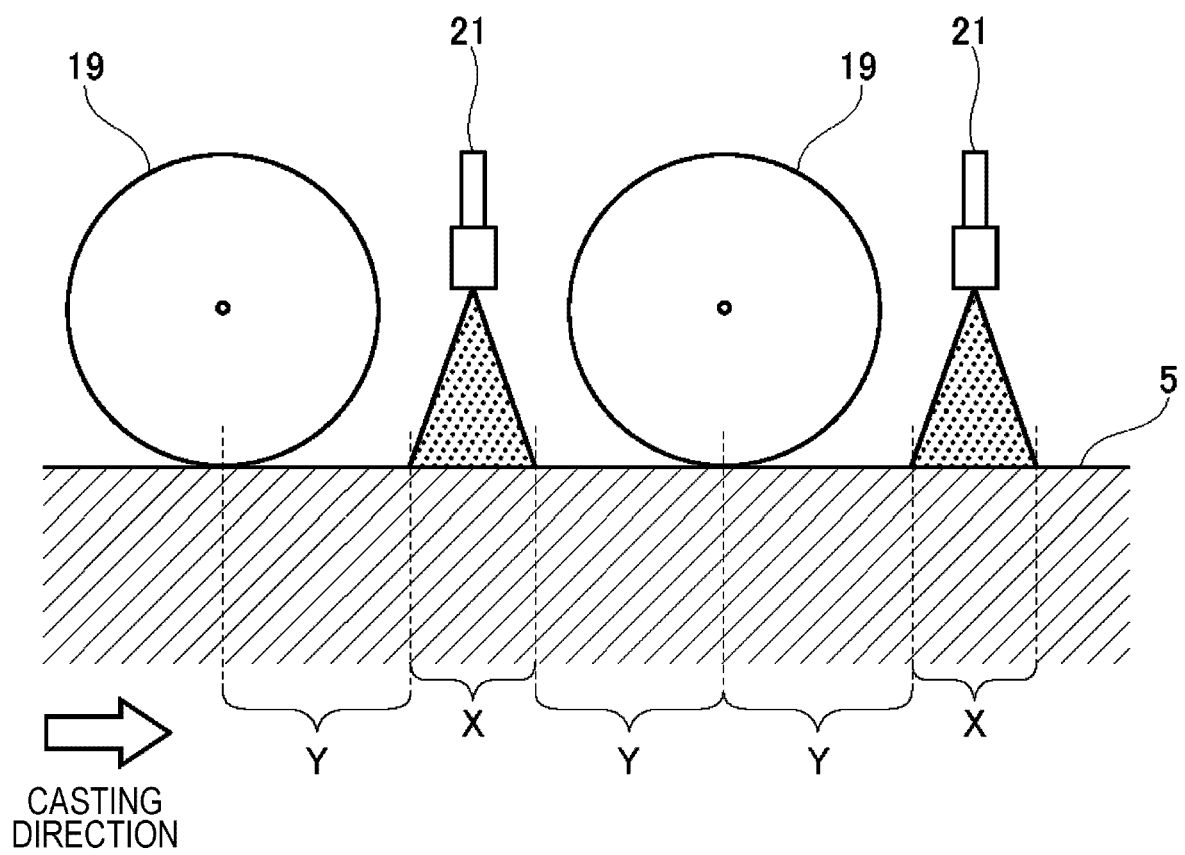


FIG. 5



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2020/040435

A. CLASSIFICATION OF SUBJECT MATTER

B22D 11/124 (2006.01) i; B22D 11/22 (2006.01) i

FI: B22D11/124 G; B22D11/124 N; B22D11/22 B

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)

B22D11/124; B22D11/22

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

Published examined utility model applications of Japan 1922-1996

Published unexamined utility model applications of Japan 1971-2020

Registered utility model specifications of Japan 1996-2020

Published registered utility model applications of Japan 1994-2020

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.
A	JP 2003-136205 A (KAWASAKI STEEL CORP.) 14 May 2003 (2003-05-14)	1-3
A	JP 2006-315044 A (NIPPON STEEL CORP.) 24 November 2006 (2006-11-24)	1-3
A	JP 2013-22620 A (NIPPON STEEL & SUMITOMO METAL CORPORATION) 04 February 2013 (2013-02-04)	1-3
A	JP 2005-103628 A (SANYO SPECIAL STEEL CO., LTD.) 21 April 2005 (2005-04-21)	1-3



Further documents are listed in the continuation of Box C.



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"&" document member of the same patent family

Date of the actual completion of the international search
22 December 2020 (22.12.2020)Date of mailing of the international search report
12 January 2021 (12.01.2021)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No. PCT/JP2020/040435
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JP 2003-136205 A	14 May 2003	(Family: none)	
JP 2006-315044 A	24 Nov. 2006	(Family: none)	
JP 2013-22620 A	04 Feb. 2013	(Family: none)	
JP 2005-103628 A	21 Apr. 2005	(Family: none)	

REFERENCES CITED IN THE DESCRIPTION

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- JP 2018015781 A [0013]