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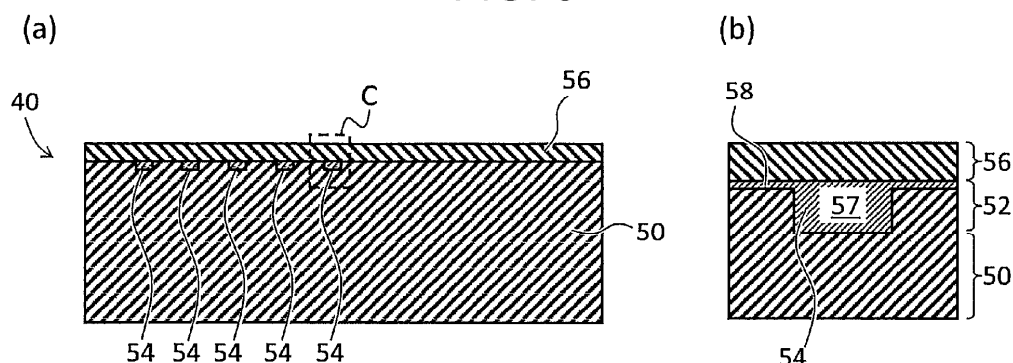
(54) **MOLD COPPER PLATE, MOLD FOR CONTINUOUS CASTING, AND CONTINUOUS STEEL CASTING METHOD**

(57) Provided is a mold copper plate capable of inhibiting non-uniform solidification of a solidifying shell, thereby inhibiting longitudinal cracking in a surface of a slab and extending the life of a continuous casting mold.

A mold copper plate for use in a continuous casting mold includes a substrate layer containing copper or a copper alloy; a layer including recessed grooves or round grooves, the layer being provided on the substrate layer; and a coating layer provided on the layer

including recessed grooves or round grooves. The coating layer includes at least one of nickel, cobalt, a nickel-based alloy, a cobalt-based alloy, a stainless steel alloy, a metal nitride, a metal carbide, and a metal oxide. The layer including recessed grooves or round grooves is formed of a different material having a ratio of a thermal conductivity of the different material to a thermal conductivity of the substrate layer of 80% or less or 120% or greater.

FIG. 3



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Description

Technical Field

- 5 **[0001]** The present invention relates to a mold copper plate for use in a continuous casting mold and also relates to a continuous casting mold and a continuous steel casting method.

Background Art

- 10 **[0002]** Regarding continuous casting of steel, when the molten steel in a mold is non-uniformly cooled, the resulting solidified shell has a non-uniform thickness in a slab casting direction and in a mold widthwise direction. When the thickness of the solidified shell is non-uniform, a stress due to the contraction and deformation of the solidified shell is exerted, and, at an early stage of solidification, this stress is concentrated on a thin portion of the solidified shell, which leads to the formation of surface cracks in the solidified shell.

- 15 **[0003]** When external forces, such as thermal stress, bending stress caused by rolls of a continuous casting machine, and straightening stress, are subsequently applied, the cracks grow into large surface cracks. In addition, in the case of medium carbon steels, such as hypo-peritectic steel, the solidified shell is deformed by δ/γ transformation at an early stage of solidification, and, consequently, the thickness of the solidified shell becomes more non-uniform, which increases the possibility of surface cracking. When the degree of non-uniformity of the thickness of the solidified
20 shell is large, longitudinal cracks may be formed in the mold, and leakage of molten steel from these longitudinal cracks, which is a phenomenon called "breakout", may occur. Cracks present in slabs cause surface defects in the subsequent step, which is a rolling step, and, therefore, it is necessary, at the stage after casting, where the steel is still in the form of a slab, to condition the surface of the slab to remove the surface cracks.

- [0004]** Patent Literature 1 discloses a continuous casting mold including different-material-filled portions, which are
25 recesses in an inner wall surface of the mold that are filled with a metal or a non-metal, the metal or the non-metal having a thermal conductivity different from the thermal conductivity of a copper plate of the mold. According to Patent Literature 1, the different-material-filled portions provided in the continuous casting mold make the thermal conductivity of the copper plate of the mold non-uniform, which inhibits non-uniform solidification at an early stage of solidification and, in turn, inhibits longitudinal cracking in the solidified shell and longitudinal cracking in the surface of the manu-
30 factured slab.

Citation List

Patent Literature

- 35 **[0005]** PTL 1: Japanese Unexamined Patent Application Publication No. 2018-192530

Summary of Invention

40 Technical Problem

- [0006]** One problem with the continuous casting mold disclosed in Patent Literature 1 is that the molten steel poured into the mold repeatedly causes thermal contraction, which leads to raising of the different-material-filled portions and formation of cracks in the different-material-filled portions and, consequently, results in a shortened life of the mold.
45 Furthermore, in cases where casting is performed at high speed in a thin slab continuous casting machine, the casting at high speed increases the temperature of the mold and, therefore, increases the likelihood of the formation of cracks not only in the different-material-filled portions but also in the surface of the mold, which results in a shortened life of the mold. In particular, regarding a funnel-shaped mold used in thin slab continuous casting machines, one problem is that the shape of the mold increases the likelihood of the formation of cracks in the mold, which results in a shortened
50 life of the mold.

- [0007]** The present invention has been made in view of the above-described problems. Accordingly, the present invention is directed to providing a mold copper plate, a continuous casting mold, and a continuous steel casting method that uses the mold; the mold copper plate is capable of inhibiting non-uniform solidification of a solidifying shell, thereby inhibiting longitudinal cracking in a surface of a slab and extending the life of a continuous casting mold.
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Solution to Problem

- [0008]** Means for solving the above-described problems are as follows.

[1] A mold copper plate for use in a continuous casting mold, the mold copper plate including a substrate layer containing copper or a copper alloy; a layer including recessed grooves or round grooves, the layer being provided on the substrate layer; and a coating layer provided on the layer including recessed grooves or round grooves, wherein the coating layer includes at least one of nickel, cobalt, a nickel-based alloy, a cobalt-based alloy, a stainless steel alloy, a metal nitride, a metal carbide, and a metal oxide, and the layer including recessed grooves or round grooves is formed of a different material having a ratio of a thermal conductivity of the different material to a thermal conductivity of the substrate layer of 80% or less or 120% or greater.

[2] The mold copper plate according to [1], further including an interfacial layer at an interface between the coating layer and the layer including recessed grooves or round grooves.

[3] A continuous casting mold including the mold copper plate described in [1] or [2], wherein the coating layer has a thickness in a stacking direction of 2.0 mm or less, and the layer including recessed grooves or round grooves is provided in a region extending 200 mm downward from a meniscus.

[4] The continuous casting mold according to [3], wherein the coating layer has a tensile strength at 300°C of 250 MPa or greater.

[5] The continuous casting mold according to [3] or [4], wherein the mold copper plate has a funnel shape.

[6] A continuous steel casting method that uses the continuous casting mold described in any one of [3] to [5], the method including adding a mold powder to a surface of molten steel present in the continuous casting mold, the mold powder having a mass ratio of CaO to SiO₂ of 0.8 or greater and 2.2 or less; and performing continuous casting at a casting speed of 1.0 m/min or greater and 6.0 m/min or less.

Advantageous Effects of Invention

[0009] In cases where a continuous casting mold including the mold copper plate of the present invention is used, non-uniform solidification of a solidifying shell can be inhibited, and the formation of cracks in the continuous casting mold during continuous casting can be inhibited. Consequently, longitudinal cracking in the surface of a slab that is cast in the continuous casting mold including the mold copper plate can be inhibited, and the life of the continuous casting mold can be extended.

Brief Description of Drawings

[0010]

[Fig. 1] Fig. 1 is a schematic cross-sectional view illustrating an example of a continuous casting machine including a continuous casting mold formed of a mold copper plate of the present embodiment.

[Fig. 2] Fig. 2 is a perspective view illustrating an example of a mold.

[Fig. 3] Fig. 3 is a cross-sectional view of the mold copper plate.

[Fig. 4] Fig. 4 is a schematic diagram of the mold copper plate, as viewed from an interior space.

[Fig. 5] Fig. 5 is a schematic diagram of a sample that was subjected to a measurement of a tensile strength.

[Fig. 6] Fig. 6 is a graph illustrating the number of longitudinal cracks in the surface of slabs of Conventional Examples 1 and 2, Invention Examples 1 to 27, and Comparative Examples 1 to 12.

[Fig. 7] Fig. 7 is a graph illustrating the number of charges, which indicates the life of a mold, of Conventional Examples 1 and 2, Invention Examples 1 to 27, and Comparative Examples 1 to 12.

Description of Embodiments

[0011] The present invention will be described below with reference to embodiments of the present invention. The embodiments described below are preferred examples of the present invention, and the present invention is in no way limited to the embodiments.

[0012] Fig. 1 is a schematic cross-sectional view illustrating an example of a continuous casting machine 10. The continuous casting machine 10 includes a continuous casting mold 12 (hereinafter referred to as "mold 12"), which is formed of a mold copper plate of the present embodiment. A continuous steel casting method that uses the mold 12, which is formed of the mold copper plate of the present embodiment, will be described first, with reference to Fig. 1.

[0013] The continuous casting machine 10 includes the mold 12, a tundish 14, which is provided above the mold 12, and multiple cast steel support rolls 16, which are arranged side by side below the mold 12. A ladle (not illustrated) for storing molten steel 18 is provided above the tundish 14. The molten steel 18 is poured into the tundish 14 from a bottom of the ladle. A submerged entry nozzle 20 is provided at a bottom of the tundish 14. The molten steel 18 is poured into the mold 12 through the submerged entry nozzle 20. The heat of the molten steel 18 is removed through an inner surface of the mold 12, and thus, the molten steel 18 is solidified to form a solidified shell (solidifying shell) 24.

Accordingly, a cast steel 28 is formed, in which the solidified shell 24 serves as an outer shell, and an unsolidified layer 26, which is formed of the molten steel 18, is present in an inner portion.

[0014] An upper surface of the molten steel 18 in the mold 12 is covered by mold flux 22, which is in a molten state. The mold flux 22 infiltrates into spaces between the mold 12 and the molten steel 18 and serves as a lubricant. The infiltration of the mold flux 22 into spaces between the mold 12 and the molten steel 18 inhibits seizure between the mold 12 and the solidified shell 24.

[0015] Immediately below the mold 12, multiple secondary cooling zones 30 are provided in a casting direction. The secondary cooling zones 30 include spray nozzles (not illustrated) disposed in spaces between cast steel support rolls 16, which are disposed adjacent to one another in a casting direction. The cast steel 28 is withdrawn from the mold 12 and then cooled by cooling water sprayed from the spray nozzles of the secondary cooling zones 30. While the cast steel 28 is conveyed on the cast steel support rolls 16 and passes through the multiple secondary cooling zones 30, the solidified shell 24 is suitably cooled to allow the solidification of the unsolidified layer 26 to proceed and, thus, the solidification of the cast steel 28 to be completed.

[0016] In a downstream region in the casting direction, multiple conveyor rolls 17 are provided for continuously conveying the cast steel 28. A cast steel cutting machine 32, which is provided to cut the cast steel 28, is disposed above the conveyor rolls 17. The cast steel 28 is cut into slabs 34 having a predetermined length by the cast steel cutting machine 32 after the cast steel 28 has been solidified. In the manner described, the slab 34 is cast by the continuous steel casting method that uses the mold 12.

[0017] Fig. 2 is a perspective view illustrating an example of the mold 12. The mold 12 is formed of a pair of mold copper plates 40 and a pair of mold copper plates 42. The mold copper plates 40 are disposed to oppose each other, and the mold copper plates 42 are held between the mold copper plates 40 and oppose each other.

[0018] The pair of mold copper plates 40 and the pair of mold copper plates 42 are formed to have a rectangular plate shape. In Fig. 2, the pair of mold copper plates 40 are disposed on a front side and on a rear side. In Fig. 2, the pair of mold copper plates 42 are disposed on a right side and on a left side.

[0019] The mold 12 has a rectangular inner wall surface formed by the pair of mold copper plates 40 and the pair of mold copper plates 42, as viewed in a top view. The mold 12 has a hollow and tubular configuration formed by the pair of mold copper plates 40 and the pair of mold copper plates 42.

[0020] The mold copper plates 40 and the mold copper plates 42 have recessed portions (not illustrated) formed in a back surface to define cooling water channels. The back surface of the mold copper plates 42 is a surface opposite to a surface of the mold 12 in an interior space, into which the molten steel 18 is poured. The mold copper plates 40 and the mold copper plates 42 are cooled by passing cooling water through the cooling water channels, and, accordingly, the molten steel 18 is cooled to form the solidified shell 24.

[0021] A "meniscus" is a position of a surface of the molten steel 18 in the mold 12. In Fig. 2, reference character M indicates the position of the meniscus. In the present embodiment, the position of the meniscus is controlled to be at a location 100 mm from an upper end of the mold 12 while continuous casting is performed. In Fig. 2, an arrow A indicates the casting direction, and an arrow B indicates a widthwise direction of the mold 12. In the mold 12, the pair of mold copper plates 40 and the pair of mold copper plates 42 are disposed such that the casting direction A and the widthwise direction B are orthogonal to each other.

[0022] The mold copper plates 40 and the mold copper plates 42 that constitute the mold 12 have the same configuration and differ only in size. Accordingly, in the description below, the configuration of the mold copper plates 40 will be described, and descriptions of the mold copper plates 42 will be omitted.

[0023] Fig. 3 is a cross-sectional view of the mold copper plate 40. Fig. 3(a) is a cross-sectional view of the mold copper plate 40, and Fig. 3(b) is an enlarged view of a C portion, which is illustrated in Fig. 3(a). As illustrated in Fig. 3, the mold copper plate 40 includes a layer 52 and a coating layer 56. The layer 52 is formed on a substrate layer 50 and includes recessed grooves 54, and the coating layer 56 is formed on the layer 52 including the recessed grooves 54. The coating layer 56 is provided on a surface of the mold 12 in the interior space, into which the molten steel 18 is poured.

[0024] The substrate layer 50 is formed of a material containing copper or a copper alloy. In the case where a copper alloy is to be used in the substrate layer 50, it is possible to use, for example, a copper alloy containing a small amount of chromium, zirconium, or the like added thereto. The layer 52 including the recessed grooves 54 is provided between the substrate layer 50 and the coating layer 56. The recessed grooves 54 are formed to be recessed from a surface of the substrate layer 50 opposite to the coating layer 56.

[0025] Fig. 4 is a schematic diagram illustrating the surface of the mold copper plate 40 in the interior space. In Fig. 4, the portion encircled by a dotted line represents an internal structure of the mold copper plate 40. Preferably, the layer 52 including the recessed grooves 54 is formed in a region R, which extends 200 mm downward from the meniscus, in the mold copper plate 40. That is, it is sufficient that the layer 52 including the recessed grooves 54 be formed in the region extending 200 mm downward from the meniscus; alternatively, the layer 52 may be formed in a region further below the location 200 mm downward from the meniscus. The layer 52 including the recessed grooves

54 may be formed in a region Q, which is located above the meniscus. As stated above, the position of the meniscus is controlled to be at a location 100 mm from the upper end of the mold 12 while continuous casting is performed. Accordingly, in the mold copper plate 40 of the present embodiment, the layer 52 including the recessed grooves 54 is formed in the region R, which extends, from the meniscus, 200 mm downward (to a location 300 mm from the upper end of the mold 12), or in the region Q, which extends, from the meniscus, 30 mm upward (to a location 70 mm from the upper end of the mold 12).

[0026] In the layer 52 including the recessed grooves 54, the recessed grooves 54 are made up of multiple vertical grooves and multiple horizontal grooves. The vertical grooves extend in the casting direction A and are arranged to be parallel to one another in the widthwise direction B. The horizontal grooves extend in the widthwise direction B and are arranged to be parallel to one another in the casting direction A. The recessed grooves 54 are recessed grooves 54 in a lattice arrangement formed by the multiple vertical grooves and horizontal grooves. Note that the arrangement of the recessed grooves 54 is not limited to a lattice arrangement. Alternatively, multiple cylindrical round grooves may be provided, for example, in a staggered arrangement in the region.

[0027] Fig. 3 is referred to again. The layer 52 including the recessed grooves 54 is formed of a different material having a ratio of a thermal conductivity of the different material to a thermal conductivity of the substrate layer 50 of 80% or less or 120% or greater. The layer 52 including the recessed grooves 54 includes filling portions 57 and a layer portion 58. The filling portions 57 are portions in which the recessed grooves 54 are filled with the different material. The layer portion 58 is made of the different material and formed between the coating layer 56 and the substrate layer 50.

[0028] The recessed grooves 54 preferably have a depth of 0.5 mm or greater and 5.0 mm or less and more preferably 1.0 mm or greater and 3.0 mm or less, with respect to the surface of the substrate layer 50. The recessed grooves 54 preferably have a width of 2.0 mm or greater and 20.0 mm or less and more preferably 4.0 mm or greater and 10.0 mm or less. The layer portion 58 preferably has a thickness in a stacking direction of 0.0 mm or greater and 0.5 mm or less and preferably 0.0 mm or greater and 0.2 mm or less.

[0029] The different material is not limited to metals and may be a non-metal. The ratio of the thermal conductivity of the different material to the thermal conductivity of the substrate layer 50, at ambient temperature (approximately 20°C), may be any value that is 80% or less or 120% or greater. In general, the thermal conductivity of metals decreases as the temperature increases. However, when the ratio of the thermal conductivity of the different material to the thermal conductivity of the substrate layer 50 at ambient temperature is 80% or less or 120% or greater, a sufficient difference in thermal conductivity can be created even at an operating temperature of the mold 12.

[0030] The different material may be a metal having a lower thermal conductivity than copper and copper alloys. For example, it is possible to use Ni (thermal conductivity: approximately 90 W/(m×K)) or an Ni alloy (heat transfer coefficient: approximately 40 to 90 W/(m×K)). Other different materials that may be used include Cu, Co, NiCo, nickel-based alloys (Hastelloy and Inconel), and stainless steel alloys. The different material for the mold copper plates 40 and 42 included in one continuous casting mold is to be only either a low-thermal-conductivity material having a ratio of the thermal conductivity thereof to the thermal conductivity of the substrate layer 50 of 80% or less or a high-thermal-conductivity material having a ratio of the thermal conductivity thereof to the thermal conductivity of the substrate layer 50 of 120% or greater.

[0031] The different material used to form the layer 52 including the recessed grooves 54 enables the thermal resistance of the mold 12 in the vicinity of the meniscus in the casting direction A and the widthwise direction B of the mold 12 to increase and decrease regularly and periodically. As a result, a distribution is formed in which a heat flux from the solidified shell to the mold 12 in the vicinity of the meniscus at an early stage of solidification of the molten steel increases and decreases regularly and periodically. This periodic increase and decrease in the heat flux reduces stress and thermal stress that are generated in the solidified shell by the transformation of δ iron to γ iron, and, consequently, deformation of the solidified shell due to the stresses is reduced. The reduction in deformation of the solidified shell enables a non-uniform heat flux distribution due to the deformation of the solidified shell to be made uniform, and, consequently, non-uniform solidification is inhibited. These effects inhibit longitudinal cracking in the surface of the solidified shell, thereby inhibiting the formation of longitudinal cracks in the surface of the cast slab 34.

[0032] It is sufficient that the coating layer 56 be provided at least on the layer 52 including the recessed grooves 54. The coating layer 56 may also be provided on a portion of the surface of the substrate layer 50 on which the layer 52 including the recessed grooves 54 is not formed. Preferably, the coating layer 56 is provided to have a thickness in the stacking direction of 2.0 mm or less. When the thickness of the coating layer 56 is 2.0 mm or less, an influence of the coating layer 56 on the heat flux is reduced, and, therefore, the effect of the periodic changes in the heat flux due to the different material can be sufficiently achieved. Preferably, the coating layer 56 is provided to have a thickness in the stacking direction of 10 μ m or greater. When the thickness of the coating layer 56 in the stacking direction is less than 10 μ m, some portions of the coating layer 56 may not be formed during the formation of the coating layer 56; accordingly, such a thickness is not preferable.

[0033] The coating layer 56 includes at least one of nickel, cobalt, a nickel-based alloy, a cobalt-based alloy, a

stainless steel alloy, a metal nitride, a metal carbide, and a metal oxide. The coating layer 56 may include Hastelloy, Inconel, or stainless steel. Since these alloys have high heat resistance and corrosion resistance, including any of these alloys improves the heat resistance and corrosion resistance of the coating layer 56.

[0034] The coating layer 56 may include at least one of a metal nitride, a metal carbide, and a metal oxide. Examples of the metal nitride include TiN, TiSiN, WN, WSiN, TaN, and TaSiN. Examples of the metal carbide include TiC, TiSiC, WC, WSiC, TaC, and TaSiC. Examples of the metal oxide include TiO and TiSiO.

[0035] In the case where the coating layer 56 includes at least one of a metal nitride, a metal carbide, and a metal oxide, the heat resistance of the coating layer 56 can be improved, and wettability between the mold flux 22 and the mold copper plate 40 can also be improved. In the case where wettability with the mold flux 22 is increased, the mold flux 22 can be uniformly introduced into the mold 12.

[0036] In the case where the mold flux 22 can be uniformly introduced into the mold 12, changes in the amount of heat removal are inhibited, which further inhibits non-uniform solidification of the solidifying shell 24. The introduced mold flux 22 causes the cooling rate at an early stage of solidification to be lowered below the cooling rate at a final stage of solidification. Accordingly, the molten steel 18 is gently cooled, which further inhibits longitudinal cracking in the surface of the slab 34. More preferably, the coating layer 56 is formed of an alloy including at least one of nickel, cobalt, a nickel-based alloy, a cobalt-based alloy, and a stainless steel alloy and further including at least one of a metal nitride, a metal carbide, and a metal oxide.

[0037] Preferably, the mold 12 formed of the mold copper plate 40 of the present embodiment has a mold thickness of 40 mm or greater and 100 mm or less and is used in a thin slab continuous casting machine that performs continuous casting at a casting speed of 3.0 m/min or greater and 6.0 m/min or less. In order to be used in such a thin slab continuous casting machine, it is preferable that the mold copper plate 40 of the present embodiment have a funnel shape. The mold copper plate having a funnel shape is a funnel-shaped mold copper plate in which a widthwise middle portion of the mold copper plate bulges, with only the thickness in the vicinity of the submerged entry nozzle 20 at a widthwise middle portion, to which the submerged entry nozzle 20 is inserted, being expanded; this is necessitated by the small width of the mold for casting a thin slab. For example, a mold copper plate having a funnel shape and a mold thickness of 40 mm is provided with a funnel-shaped portion, which is a widthwise middle portion of the mold copper plate that has been expanded to have a funnel shape, so that a submerged entry nozzle 20 having an outside diameter ϕ of 80 to 100 mm can be used.

[0038] In the case of thin slab continuous casting machines, which perform casting at high speed, the mold temperature in the vicinity of the meniscus increases, which promotes non-uniform solidification and in turn increases the likelihood that the cast slab 34 has longitudinal cracks in the surface. In the mold copper plate having a funnel shape, thermal stress is likely to be generated in the bulged widthwise middle portion, and heat removal from the molten steel 18 at this location is non-uniform. Accordingly, in molds including the mold copper plate having a funnel shape, non-uniform solidification of the solidifying shell is further promoted, which further increases the likelihood that the cast slab 34 has longitudinal cracks in the surface.

[0039] The mold copper plate 40 of the present embodiment, in contrast, includes the layer 52 including the recessed grooves 54 and formed of a different material having a ratio of a thermal conductivity of the different material to a thermal conductivity of the substrate layer 50 of 80% or less or 120% or greater. Accordingly, non-uniform solidification of the solidifying shell 24 is inhibited, and, consequently, longitudinal cracking in the surface of the cast slab 34 can be inhibited. Furthermore, the mold copper plate 40 of the present embodiment includes the coating layer 56, which contains at least one of nickel, cobalt, a nickel-based alloy, a cobalt-based alloy, a stainless steel alloy, a metal nitride, a metal carbide, and a metal oxide. As a result, even when a surface temperature in the vicinity of the meniscus is increased because of the casting at high speed, the formation of cracks in the coating layer 56 can be inhibited. Since the coating layer 56 is provided on the layer 52 including the recessed grooves 54, the inhibition of the formation of cracks in the coating layer 56 results in the inhibition of the formation of cracks in the different material present in the layer under the coating layer 56.

[0040] In the case of a thin slab continuous casting machine that performs continuous casting at a high casting speed of 3.0 m/min or greater and 6.0 m/min or less, the surface temperature of the mold copper plate that constitutes the mold 12 may reach approximately 300°C during casting. When the surface temperature of the mold copper plate that constitutes the mold reaches 300°C, a strength of the coating layer decreases, and, consequently, the life of the mold may significantly decrease even when the mold copper plate has a coated surface.

[0041] It is preferable that the mold copper plate 40 include a coating layer 56 having a tensile strength at 300°C of 250 MPa or greater so that the life does not significantly decrease even when the surface temperature reaches 300°C or greater. In the case where the mold copper plate 40 includes a coating layer 56 having a tensile strength at 300°C of 250 MPa or greater, the formation of cracks in the coating layer 56 is inhibited even when the mold copper plate 40 is used in a thin slab continuous casting machine including a mold in which the surface temperature can be 300°C or greater; consequently, a decrease in the life of the mold can be inhibited.

[0042] Fig. 5 is a schematic diagram of a sample that was subjected to a measurement of a tensile strength. The

tensile strength at 300°C of the coating layer 56 can be measured by a method described in JIS G 0567:2020 (Method of elevated temperature tensile test for steels and heat-resisting alloys). It has been confirmed that Hastelloy, Inconel, stainless steel, metal nitrides (TiN, TiSiN, WN, WSiN, TaN, and TaSiN), and metal carbides (TiC, TiSiC, WC, WSiC, TaC, and TaSiC) are unlikely to have reduced tensile strength even when the temperature reaches 300°C or greater, with their tensile strengths at 300°C being 250 MPa or greater.

[0043] In the case where the coating layer 56 is provided on the layer 52 including the recessed grooves 54, it is preferable that an interfacial layer be formed at an interface between the coating layer 56 and the layer 52 including the recessed grooves 54. In the case where an interfacial layer is present at an interface between the coating layer 56 and the layer 52 including the recessed grooves 54, the formation of a gap and irregularities at the interface can be inhibited even when the surface temperature of the mold copper plate 40 reaches 300°C or greater.

[0044] Using a laser cladding method to provide the coating layer 56 on the layer 52 including the recessed grooves 54 results in the formation of the interfacial layer. On the other hand, using electroplating or hot dip coating to provide the coating layer 56 does not result in the formation of the interfacial layer.

[0045] A cross section of a sample including a TiC coating layer provided on a surface of a copper alloy, which was the substrate, was examined. The coating layer was provided by using a laser cladding method. Thus, it was confirmed that an interfacial layer had been formed at an interface between the substrate and the coating layer; in the interfacial layer, the copper alloy, which constituted the substrate, had been mixed with the TiC, which constituted the coating layer. In contrast, in a sample including a coating layer formed by hot dip coating, no such interfacial layer had been formed, and, at the interface, the copper alloy, which constituted the substrate, and the TiC, which constituted the coating layer, had been separated from each other without being mixed. From these results, it was confirmed that it is preferable that an interfacial layer be formed at an interface between the coating layer 56 and the layer 52 including the recessed grooves 54, and it was also confirmed that, consequently, separation and deformation at interfacial portions can be inhibited.

[0046] Regarding a continuous steel casting method that uses a mold including the mold copper plate of the present embodiment, a mold powder that is used preferably has a basicity (mass ratio of CaO to SiO₂) of 0.8 or greater and 2.2 or less, and a casting speed is preferably 1.0 m/min or greater and 6.0 m/min or less. In cases where these continuous casting conditions are used, performing continuous casting with a mold including the mold copper plate of the present embodiment enables slabs to be continuously cast while longitudinal cracking in surfaces thereof is inhibited and also enables the life of the continuous casting mold to be extended.

[0047] As described above, the mold copper plate 40 of the present embodiment includes the layer 52, which is provided on the substrate layer 50 and includes the recessed grooves 54, and the coating layer 56, which is provided on the layer 52 including the recessed grooves 54. The layer 52 including the recessed grooves 54 is formed of a different material having a ratio of a thermal conductivity of the different material to a thermal conductivity of the substrate layer 50 of 80% or less or 120% or greater. Accordingly, non-uniform solidification of the solidifying shell is inhibited, and, consequently, longitudinal cracking in the surface of the cast slab 34 can be inhibited.

[0048] The coating layer 56 includes at least one of nickel, cobalt, a nickel-based alloy, a cobalt-based alloy, a stainless steel alloy, a metal nitride, a metal carbide, and a metal oxide. Accordingly, the coating layer has improved heat resistance, and the mold copper plate has improved heat resistance; thus, even when the surface temperature of the mold copper plate 40 is increased, the formation of cracks in the coating layer 56 is inhibited. In addition, since the coating layer 56 is provided on the layer 52 including the recessed grooves 54 and formed of a different material, the formation of cracks in the different material can also be inhibited. As a result of these, the life of the mold 12 formed of the mold copper plates 40 and 42 can be extended.

[0049] In the present embodiment, an example has been described in which the mold 12 is formed of a pair of mold copper plates 40 and a pair of mold copper plates 42. Note that this is a non-limiting example. As described above, since the mold copper plate of the present embodiment can inhibit longitudinal cracking in the surface of the cast slab 34 and also can inhibit the formation of cracks, it is sufficient that at least one of the mold copper plates that constitute the mold 12 be the mold copper plate 40 or 42 of the present embodiment. In this case, longitudinal cracking in the surface of the cast slab 34 can be inhibited, and the life of the mold can be extended, compared with molds including none of the mold copper plates 40 and 42 of the present embodiment.

EXAMPLES

[0050] Described below are Examples in which medium carbon steel, which had been subjected to oxygen blowing in a converter and then to an RH degassing process, was continuously cast to form slabs by casting. The medium carbon steel used in the Examples had a chemical composition containing C: 0.08 to 0.17 mass%, Si: 0.10 to 0.30 mass%, Mn: 0.50 to 1.20 mass%, P: 0.010 to 0.030 mass%, S: 0.005 to 0.015 mass%, and Al: 0.020 to 0.040 mass%. 300 tons of the medium carbon steel was introduced into a ladle and was continuously cast in a continuous casting machine as illustrated in Fig. 1.

[0051] In Invention Examples 1 to 27, a mold formed of a mold copper plate that included the coating layer and the layer including recessed grooves was used. In Invention Examples 1 to 27, the layer including recessed grooves was formed with a different material having a ratio of the thermal conductivity at ambient temperature of the different material to that of the substrate layer of 80% or less or 120% or greater. In Invention Examples 1 to 18, 25, and 27, an interfacial layer was formed at an interface between the coating layer and the layer including recessed grooves, by providing the coating layer by using a laser cladding method. In contrast, in Invention Examples 19 to 24 and 26, the formation of the interfacial layer at an interface between the coating layer and the layer including recessed grooves was prevented by providing the coating layer by using electroplating.

[0052] In the Conventional Examples, a mold formed of a mold copper plate that included a coating layer of Ni or NiCo formed by electroplating was used. In Comparative Example 1, a mold formed of a mold copper plate that included only the substrate layer was used. In Comparative Examples 2 to 12, a mold formed of a mold copper plate that included a coating layer provided by using a laser cladding method was used. In Comparative Examples 9 to 12, a mold formed of a mold copper plate in which the layer including recessed grooves was formed with a different material was used; the ratio of the thermal conductivity at ambient temperature of the different material to that of the substrate layer was greater than 80% or less than 120%. Conditions for the continuous casting and the results of evaluation of the cast slabs of the Conventional Examples, Invention Examples, and Comparative Examples are shown in Table 1 below. In Table 1, in the column "Coating Layer of Mold Steel Plate", "%" means mass%, and "TiC10%-Ni" of Invention Example 6 means a Ni alloy containing 10 mass% TiC.

[Table 1]

	Coating Layer of Mold Copper Plate	Ratio of Thermal Conductivity of Different Material to Thermal Conductivity of Substrate Layer	Tensile Strength of Coating Layer at 300°C	Interfacial Layer	Mold Powder (CaO/SiO ₂)	Mold Temperature During Casting	Casting Speed	Number of Longitudinal Cracks in Surface of Slab	Number of Charges
		%	MPa	Yes/No	-	°C	m/min	number/m ²	ch-number
Conventional Example 1	Ni	-	240	No	1.3	280	2.3	1.21	700
Conventional Example 2	NiCo	-	230	No	1.5	282	2.3	0.90	950
Invention Example 1	Ni	73.3	240	Yes	1.1	295	2.3	0.12	1100
Invention Example 2	NiCo	73.3	230	Yes	1.1	296	1.0	0.08	1200
Invention Example 3	TiC	73.3	500	Yes	1.3	310	2.6	0.12	1350
Invention Example 4	TiO	73.3	510	Yes	1.5	305	3.0	0.12	1340
Invention Example 5	TiN	73.3	490	Yes	2.2	315	2.8	0.11	1320
Invention Example 6	TiC10%-Ni	73.3	530	Yes	1.6	305	3.2	0.11	1320
Invention Example 7	TiO10%-Ni	73.3	540	Yes	1.5	306	3.5	0.12	1330
Invention Example 8	TiN10%-Ni	73.3	520	Yes	2.2	308	2.5	0.13	1350
Invention Example 9	TiC10%-Co	73.3	530	Yes	1.8	304	4.0	0.11	1310
Invention Example 10	TiO10%-Co	60.0	540	Yes	2.1	305	4.6	0.12	1320
Invention Example 11	TiN10%-Co	73.3	560	Yes	1.0	305	4.2	0.13	1360

(continued)

	Coating Layer of Mold Copper Plate	Ratio of Thermal Conductivity of Different Material to Thermal Conductivity of Substrate Layer	Tensile Strength of Coating Layer at 300°C	Interfacial Layer	Mold Powder (CaO/SiO ₂)	Mold Temperature During Casting	Casting Speed	Number of Longitudinal Cracks in Surface of Slab	Number of Charges
		%	MPa	Yes/No	-	°C	m/min	number/m ²	ch-number
Invention Example 12	TiN10%-Hastelloy	73.3	600	Yes	1.2	315	6.0	0.11	1510
Invention Example 13	TiC10%-Hastelloy	60.0	590	Yes	1.5	314	5.8	0.10	1520
Invention Example 14	TiO10%-Hastelloy	73.3	610	Yes	1.1	320	6.0	0.12	1500
Invention Example 15	TiN10%-Inconel	73.3	600	Yes	1.2	320	5.5	0.11	1530
Invention Example 16	TiC10%-Inconel	60.0	590	Yes	1.3	314	6.0	0.10	1510
Invention Example 17	TiO10%-Inconel	73.3	610	Yes	2.0	315	6.0	0.09	1500
Invention Example 18	TiC40%-Stainless Steel	73.3	620	Yes	2.2	320	4.2	0.10	1540
Invention Example 19	TiC10%-Ni	27.3	600	No	1.6	310	5.0	0.21	950
Invention Example 20	TiO10%-Ni	73.3	590	No	1.5	320	5.5	0.23	900
Invention Example 21	TiN10%-Ni	73.3	610	No	2.2	330	6.0	0.25	850
Invention Example 22	TiN10%-Hastelloy	73.3	595	No	1.2	320	5.0	0.26	880
Invention Example 23	TiN10%-Inconel	27.3	600	No	1.2	310	4.9	0.24	850

(continued)

	Coating Layer of Mold Copper Plate	Ratio of Thermal Conductivity of Different Material to Thermal Conductivity of Substrate Layer	Tensile Strength of Coating Layer at 300°C	Interfacial Layer	Mold Powder (CaO/SiO ₂)	Mold Temperature During Casting	Casting Speed	Number of Longitudinal Cracks in Surface of Slab	Number of Charges
		%	MPa	Yes/No	-	°C	m/min	number/m ²	ch-number
Invention Example 24	TiN10%-Stainless Steel	73.3	605	No	1.5	300	5.8	0.22	880
Invention Example 25	TiN10%-Inconel	125.0	600	Yes	1.2	320	5.5	0.13	1535
Invention Example 26	TiN10%-Stainless Steel	130.0	605	No	1.5	300	5.8	0.24	895
Invention Example 27	TiC10%-Inconel	140.0	590	Yes	1.3	314	6.0	0.09	1520
Comparative Example 1	No	-	-	No	1.5	270	2.3	1.62	550
Comparative Example 2	TiN	-	490	Yes	2.2	305	2.8	0.81	1200
Comparative Example 3	TiC	-	500	Yes	1.3	310	2.6	0.65	1120
Comparative Example 4	TiO	-	510	Yes	1.5	305	3.0	0.66	1140
Comparative Example 5	TiC10%-Inconel	-	600	Yes	1.2	320	5.5	0.70	1150
Comparative Example 6	TiC10%-Stainless Steel	-	620	Yes	2.2	320	4.2	0.67	1100
Comparative Example 7	TiC10%-Inconel	-	600	Yes	2.0	320	6.0	0.74	1130

(continued)

	Coating Layer of Mold Copper Plate	Ratio of Thermal Conductivity of Different Material to Thermal Conductivity of Substrate Layer	Tensile Strength of Coating Layer at 300°C	Interfacial Layer	Mold Powder (CaO/SiO ₂)	Mold Temperature During Casting	Casting Speed	Number of Longitudinal Cracks in Surface of Slab	Number of Charges
		%	MPa	Yes/No	-	°C	m/min	number/m ²	ch-number
Comparative Example 8	TiC10%-Stainless Steel	-	620	Yes	2.2	320	4.2	0.69	1150
Comparative Example 9	TiC10%-Inconel	88.9	590	Yes	1.2	314	6.0	0.35	1510
Comparative Example 10	TiC	114.3	500	Yes	1.3	310	2.6	0.34	1200
Comparative Example 11	TiC10%-Ni	88.9	600	Yes	1.6	310	5.0	0.33	960
Comparative Example 12	TiC10%-Hastelloy	114.3	590	Yes	1.5	314	5.8	0.36	1500

[0053] The tensile strength at 300°C of the coating layer is a value measured by the method described in JIS G 0567:2020 (Method of elevated temperature tensile test for steels and heat-resisting alloys). The mold temperature during casting is the maximum value of the surface temperatures in the vicinity of the meniscus measured by a thermocouple installed within the mold copper plates. The number of longitudinal cracks in the surface of a slab is the value obtained by measuring the number of longitudinal cracks in the surface that were formed in the slab after casting. The number of charges is the number of total charges during the time from when the mold began to be used to when a crack was formed in the surface of the mold.

[0054] Fig. 6 is a graph illustrating the number of longitudinal cracks in the surface of the slabs of Conventional Examples 1 and 2, Invention Examples 1 to 27, and Comparative Examples 1 to 12. As indicated by Fig. 6, the number of longitudinal cracks in the surface of the slabs of Invention Examples 1 to 27 was significantly smaller than those of Conventional Examples 1 and 2 and Comparative Examples 1 to 12. This result confirmed that in the case where the layer including recessed grooves is formed with a different material having a ratio of the thermal conductivity of the different material to the thermal conductivity of the substrate layer of 80% or less or 120% or greater, longitudinal cracking in the surface of the solidified shell can be inhibited and that, consequently, longitudinal cracking in the surface of the cast slab can be inhibited.

[0055] Fig. 7 is a graph illustrating the number of charges, which indicates the life of a mold, of Conventional Examples 1 and 2, Invention Examples 1 to 27, and Comparative Examples 1 to 12. As indicated by Fig. 7, it was confirmed that the number of charges of Invention Examples 1 to 27 was comparable to or higher than those of Conventional Examples 1 and 2 and Comparative Example 1. This result confirmed that in the case where a mold formed of any of the mold copper plates of Invention Examples 1 to 27 is used, the formation of longitudinal cracks in the surface of the slab can be inhibited without reducing the life of the mold compared with conventional molds.

[0056] Invention Examples 19 to 24 and 26 are invention examples in which mold copper plates that had no interfacial layer formed at an interface between the coating layer and the layer including recessed grooves were used. As indicated by Fig. 7, the number of charges of Invention Examples 1 to 18, 25, and 27, in which the mold copper plates having an interfacial layer formed at an interface between the coating layer and the layer including recessed grooves were used, was greater than the number of charges of Invention Examples 19 to 24 and 26, in which the mold copper plates that did not have the interfacial layer were used. This result confirmed that in the case where a mold copper plate having an interfacial layer at an interface between the coating layer and the layer including recessed grooves is used, the life of the mold can be extended.

[0057] Invention Examples 1 and 2 are invention examples in which mold copper plates including a coating layer that did not satisfy the tensile strength at 300°C of 250 MPa or greater were used. Invention Examples 3 to 18, 25, and 27 are invention examples in which mold copper plates including a coating layer that satisfied the tensile strength at 300°C of 250 MPa or greater were used. As indicated by Fig. 7, the number of charges of Invention Examples 3 to 18, 25, and 27 was greater than the number of charges of Invention Examples 1 and 2. This result confirmed that in the case where a mold copper plate including a coating layer that satisfies the tensile strength at 300°C of 250 MPa or greater is used, the life of the mold can be further extended.

Reference Signs List

[0058]

- 10 continuous casting machine
- 12 continuous casting mold
- 14 tundish
- 16 cast steel support roll
- 17 conveyor roll
- 18 molten steel
- 20 submerged entry nozzle
- 22 mold flux
- 24 solidified shell (solidifying shell)
- 26 unsolidified layer
- 28 cast steel
- 30 secondary cooling zone
- 32 cast steel cutting machine
- 34 slab
- 40 mold copper plate
- 42 mold copper plate
- 50 substrate layer

52 layer including recessed grooves
 54 recessed grooves
 56 coating layer
 57 filling portion
 58 layer portion

Claims

1. A mold copper plate for use in a continuous casting mold, the mold copper plate comprising:

a substrate layer containing copper or a copper alloy;
 a layer including recessed grooves or round grooves, the layer being provided on the substrate layer; and
 a coating layer provided on the layer including recessed grooves or round grooves, wherein
 the coating layer includes at least one of nickel, cobalt, a nickel-based alloy, a cobalt-based alloy, a stainless
 steel alloy, a metal nitride, a metal carbide, and a metal oxide, and
 the layer including recessed grooves or round grooves is formed of a different material having a ratio of a
 thermal conductivity of the different material to a thermal conductivity of the substrate layer of 80% or less or
 120% or greater.

2. The mold copper plate according to claim 1, further comprising an interfacial layer at an interface between the
 coating layer and the layer including recessed grooves or round grooves.

3. A continuous casting mold comprising the mold copper plate described in claim 1 or 2, wherein

the coating layer has a thickness in a stacking direction of 2.0 mm or less, and
 the layer including recessed grooves or round grooves is provided in a region extending 200 mm downward
 from a meniscus.

4. The continuous casting mold according to claim 3,
 wherein the coating layer has a tensile strength at 300°C of 250 MPa or greater.

5. The continuous casting mold according to claim 3 or 4, wherein the mold copper plate has a funnel shape.

6. A continuous steel casting method that uses the continuous casting mold described in any one of claims 3 to 5,
 the method comprising:

adding a mold powder to a surface of molten steel present in the continuous casting mold, the mold powder
 having a mass ratio of CaO to SiO₂ of 0.8 or greater and 2.2 or less; and
 performing continuous casting at a casting speed of 1.0 m/min or greater and 6.0 m/min or less.

FIG. 1

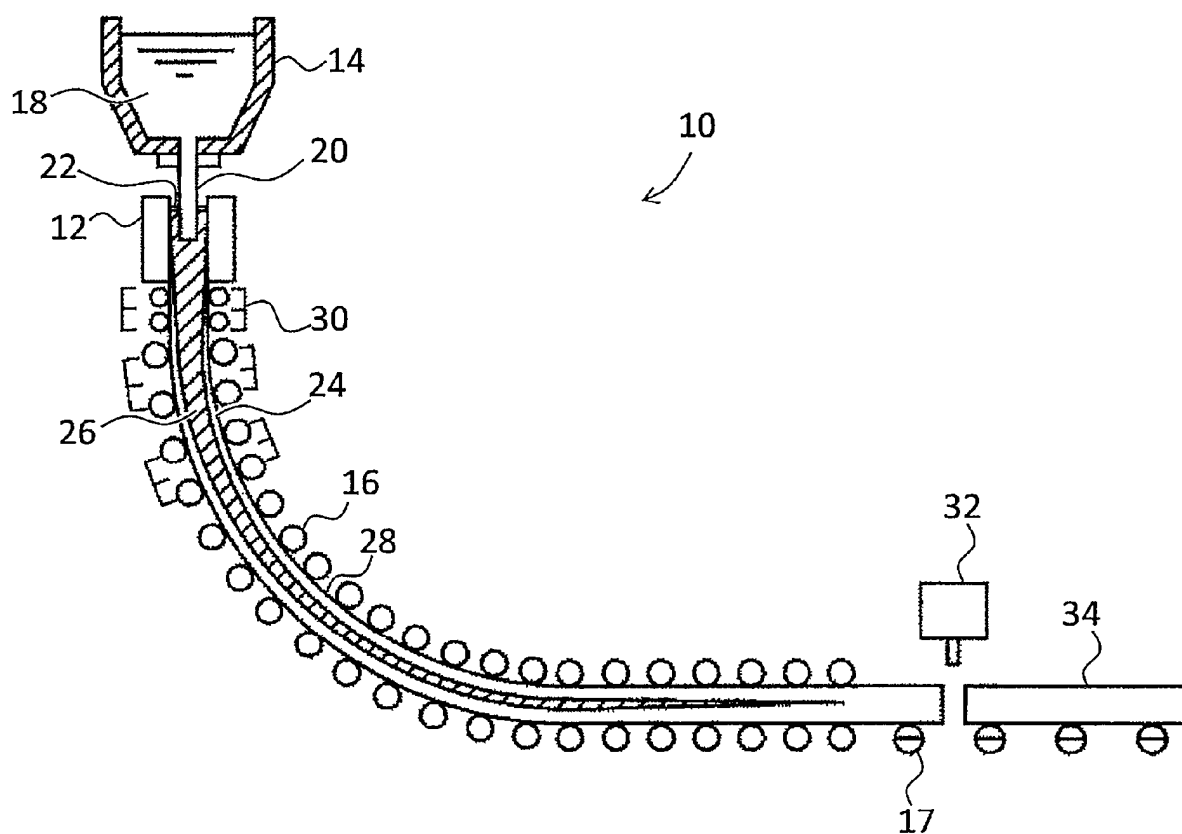


FIG. 2

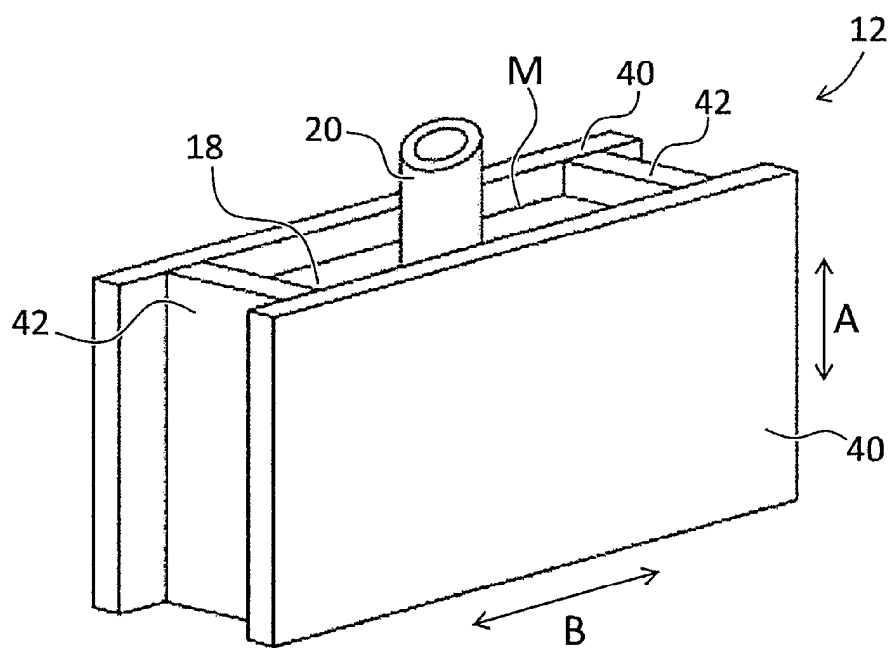


FIG. 3

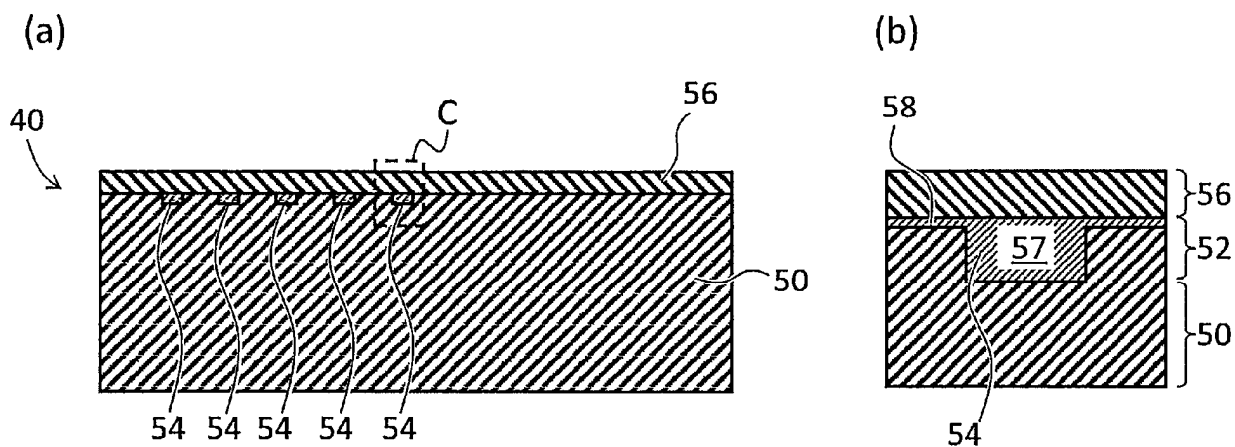


FIG. 4

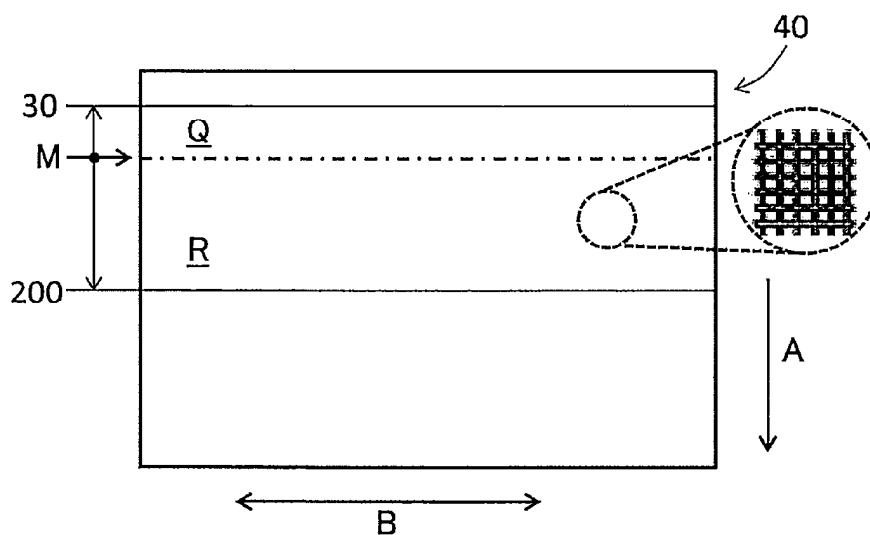


FIG. 5

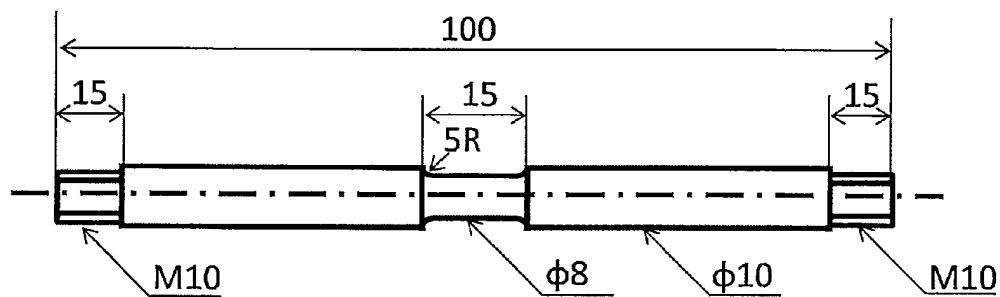


FIG. 6

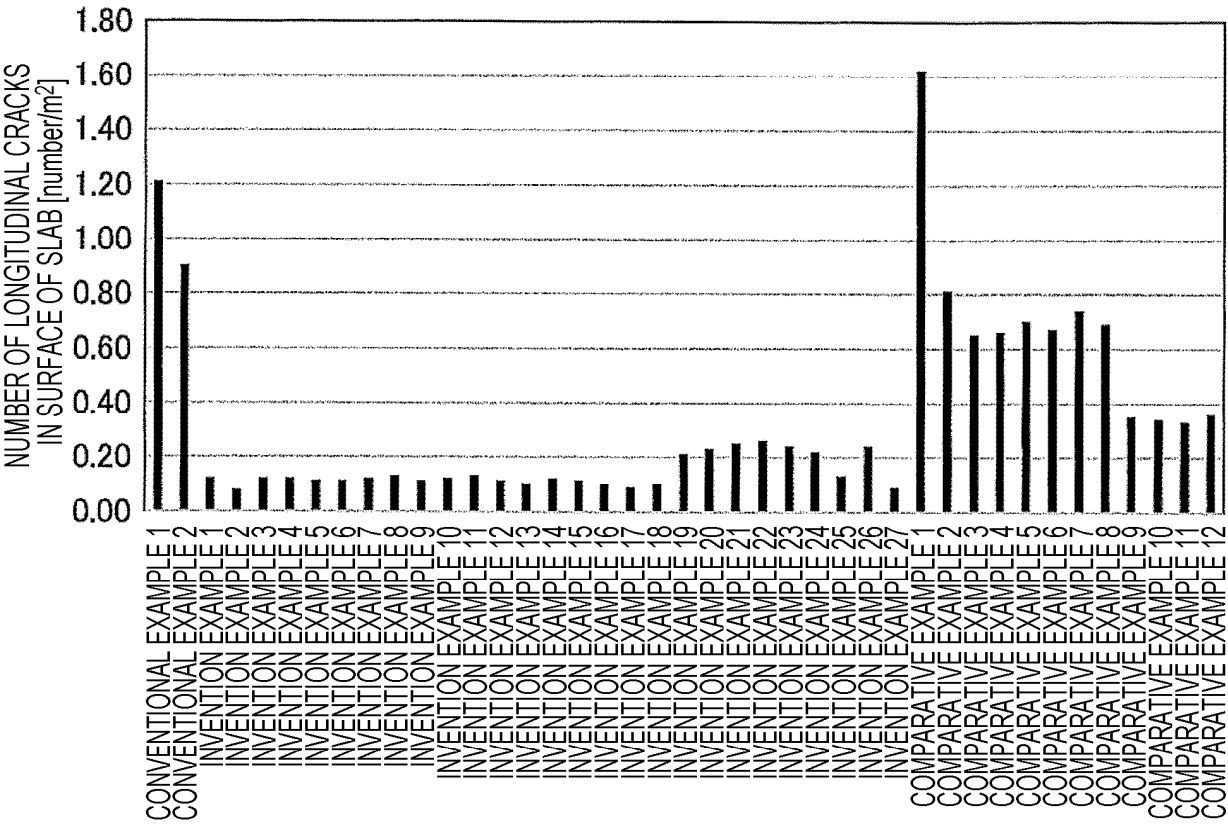
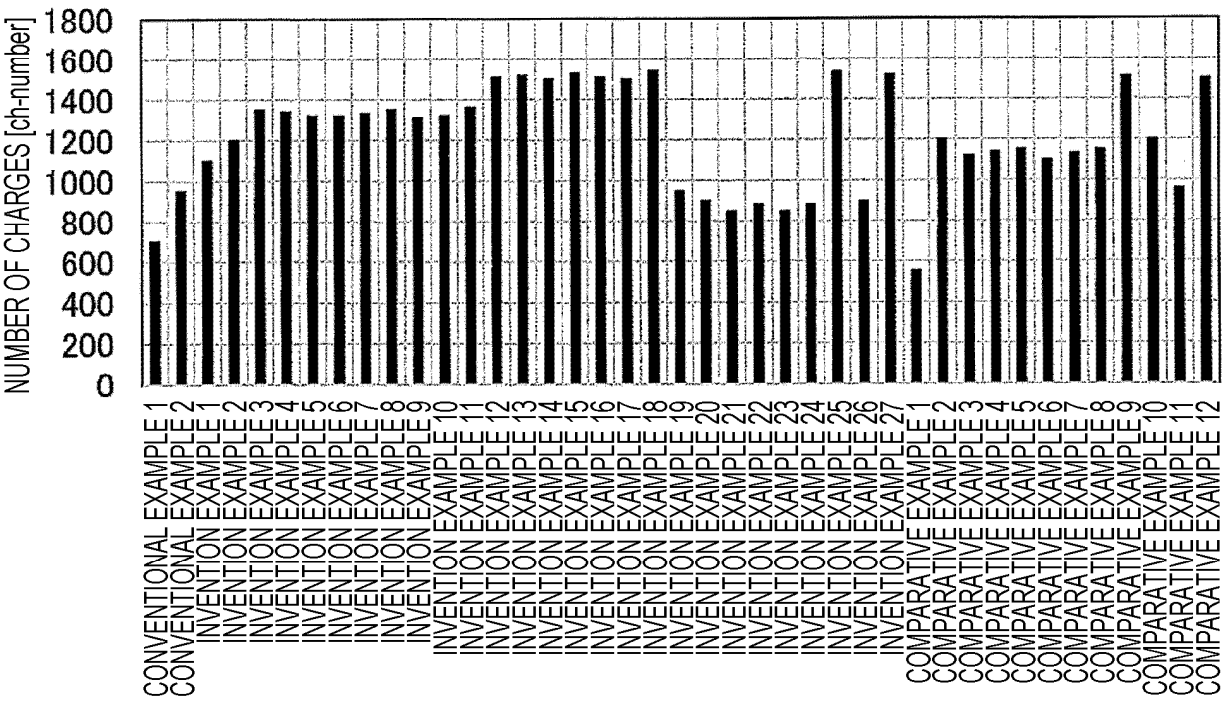


FIG. 7



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2025/002489

A. CLASSIFICATION OF SUBJECT MATTER

B22D 11/059(2006.01)i

FI: B22D11/059 110A; B22D11/059 110H

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)

B22D11/059

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 1971-2025
 Registered utility model specifications of Japan 1996-2025
 Published registered utility model applications of Japan 1994-2025

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2018/074406 A1 (JFE STEEL CORPORATION) 26 April 2018 (2018-04-26) claims, paragraphs [0022]-[0046], fig. 1-4	1
Y		1-6
X	WO 2016/067578 A1 (JFE STEEL CORPORATION) 06 May 2016 (2016-05-06) claims, paragraphs [0015]-[0034], fig. 1-4	1
Y		1-6
Y	JP 2012-045591 A (MISHIMA KOSAN CO., LTD.) 08 March 2012 (2012-03-08) claims, paragraphs [0024], [0033]-[0034]	1-6
Y	JP 2021-070060 A (JFE STEEL CORPORATION) 06 May 2021 (2021-05-06) claims	2
Y	WO 2013/069121 A1 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 16 May 2013 (2013-05-16) claims, paragraph [0029], fig. 1-5	5

☒ 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

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Name and mailing address of the ISA/JP

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2025/002489

C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	JP 2017-024079 A (JFE STEEL CORPORATION) 02 February 2017 (2017-02-02) claims, paragraph [0102], fig. 1-5	6

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/JP2025/002489

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REFERENCES CITED IN THE DESCRIPTION

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