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(54) CONTINUOUS CASTING EQUIPMENT FOR TITANIUM OR TITANIUM ALLOY SLAB

(57) The surface of a molten metal (12) that has been poured into a mold (2) is heated using a plasma arc generated by a plasma torch (7). The surface or the vicinity of the surface of the molten metal (12) is electromagnetically stirred with EMS (8) provided on the sides of the mold (2), thereby making it possible to cast slabs with few surface defects.

FIG. 4A

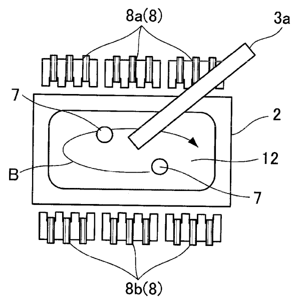


FIG. 4B

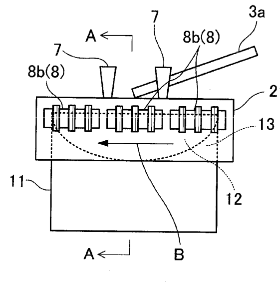
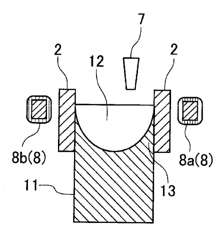


FIG. 4C



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Description

TECHNICAL FIELD

[0001] The invention relates to a continuous casting apparatus for a slab (cast slab) made of titanium or titanium alloy.

BACKGROUND ART

[0002] Slab continuous casting is carried out in such a manner that, while metal molten by vacuum arc melting or by electron beam melting is charged into a bottomless rectangular-shaped mold and the molten metal is solidified therein, the solidified molten metal is pulled out downward therefrom to thereby produce a metal slab continuously.

[0003] A mold vibration detector disclosed in the patent reference 1, for smooth pull-out of the metal slab, when a mold is vibrated in the pull-out direction, detects the vibrations of the mold generated in a direction perpendicular to the pull-out direction using a position sensor. By checking according to the amount of vibrations in a direction perpendicular to the pull-out direction whether the casting is good or not, the quality of the slab can be stabilized.

CITATION LIST

PATENT REFERENCE

[0004] Patent Reference 1: JP-A-2004-136368

SUMMARY OF THE INVENTION

PROBLEMS THAT THE INVENTION IS TO SOLVE

[0005] Here, when a slab of titanium or titanium alloy has irregularities or flaws on its surface after continuous casting, they cause surface detects in a next process, namely, in a rolling process. Thus, before rolling, the irregularities or flaws of the slab surface must be removed by cutting or the like. However, this drops the yield rate and increases the number of operation processes, thereby increasing the cost of the slab. Therefore, it is required to cast a slab having no irregularities or flaws on its surface.

[0006] Now, it can be guessed that such slab surface defects are caused to occur because a solidified shell grows excessively in the vicinity of the wall surfaces of the mold and is exposed to the surface of the molten metal to thereby cover it. Thus, in order to restrict the growth of the solidified shell in the vicinity of the wall surface of the mold, it is necessary to increase the output of a heating device and thus increase the amount of heat input into the surface of the molten metal to thereby melt the solidified shell again. However, since heat dissipates greatly in the vicinity of the surface of the molten titanium and also titanium has low heat conductivity, the initial solidified shell cannot be melted sufficiently.

[0007] This can indicate an idea that, by stirring the molten titanium, the high-temperature molten titanium is caused to flow to the vicinity of the wall surface of the mold to thereby melt the initial solidified shell. However, since titanium is active metal, it is difficult to stir the molten titanium by inserting a device such as a propeller therein or to stir it by blowing a gas therein. Also, in electron beam melting, since electron beams can be easily influenced by a magnetic field, electromagnetic stirring is also difficult.

[0008] It is an object of the invention to provide a continuous casting apparatus for a slab made of titanium or titanium alloy which can cast a slab having reduced defects on its surface.

MEANS FOR SOLVING THE PROBLEMS

[0009] A continuous casting apparatus for a slab formed of titanium or titanium alloy according to the invention charges molten metal constituted of molten titanium or titanium alloy into a bottomless rectangular-shaped mold, solidifies the molten metal therein and draws out the solidified molten metal, thereby continuously casting a slab formed of titanium or titanium alloy. The continuous casting apparatus includes: a plasma arc heating device configured to heat the surface of the molten metal charged into the mold using plasma arcs; and at least one electromagnetic stirring device configured to stir the surface of the molten metal or the vicinity of the surface by electromagnetic induction using an alternating current.

[0010] According to the above structure, the surface of the molten metal charged into the mold is heated by the plasma arcs. In the case of the plasma arcs, since they will not be influenced by a magnetic field in other areas than the vicinity of a plasma jet flow, electromagnetic stirring is possible which is difficult in electron beam melting easily influenced by the magnetic field. Thus, by stirring the surface of the molten metal or the vicinity thereof by electromagnetically, heat is transferred to a solidified shell in the vicinity of the wall surface of the mold to warm such shell, which restricts the growth of the solidified shell in the vicinity of the wall surface of the mold to thereby restrict the occurrence of defects on the surface of the slab caused by the growth of the solidified shell in the vicinity of the wall surface of the mold. This makes it possible to cast a slab having reduced defects on its surface.

[0011] Also, in the continuous casting apparatus for a slab formed of titanium or titanium alloy according to the invention, the electromagnetic stirring device may be arranged on the periphery of the mold. According to the above structure, by arranging the electromagnetic stirring device on the periphery of the mold, the surface of the molten metal or the vicinity thereof can be stirred without obstructing the heating to be carried out by the plasma arcs.

[0012] In the continuous casting apparatus for a slab formed of titanium or titanium alloy according to the invention, the electromagnetic stirring device may generate a flow moving parallel to the wall surface of the mold in the surface of the molten metal or in the vicinity of the surface. According to the above structure, by generating the flow moving parallel to the wall surface of the mold in the surface of the molten metal or in the vicinity thereof, a heat transfer coefficient between the solidified shell in the vicinity of the wall of the mold and molten metal can be increased. This can restrict properly the growth of the solidified shell in the vicinity of the mold wall surface.

[0013] In the continuous casting apparatus for a slab formed of titanium or titanium alloy according to the invention, the electromagnetic stirring device may generate a flow turning in the horizontal direction in the surface of the molten metal or in the vicinity of the surface. According to the above structure, by generating, in the surface of the molten metal or in the vicinity thereof, the flow turning horizontally within the mold, a flow moving parallel to the mold wall surface can be properly generated in the surface of the molten metal or in the vicinity thereof.

[0014] In the continuous casting apparatus for a slab formed of titanium or titanium alloy according to the invention, the electromagnetic stirring device may generate a flow colliding with the mold wall surface in the surface of the molten metal or in the vicinity of the surface. According to the above structure, by generating, in the surface of the molten metal or in the vicinity thereof, the flow colliding with the mold wall surface, a heat input amount into the solidified shell in the vicinity of the mold wall surface can be increased. This can restrict properly the growth of the solidified shell in the vicinity of the mold wall surface.

[0015] In the continuous casting apparatus for a slab formed of titanium or titanium alloy according to the invention, the electromagnetic stirring device may generate a flow moving down along the mold wall surface in the molten metal. According to the above structure, by generating in the molten metal the flow moving along the mold wall surface, there is generated in the molten metal a flow which turns in the vertical direction. Due to this vertically turning flow, a flow colliding with the mold wall surface can be properly generated in the surface of the molten metal or in the vicinity thereof.

[0016] In the continuous casting apparatus for a slab formed of titanium or titanium alloy according to the invention, the electromagnetic stirring device may generate a pair of flows turning in the vertical direction and also turning in the mutually opposite directions in the molten metal, to thereby generate a pair of flows respectively colliding with the two opposed wall surfaces of the mold in the surface of the molten metal or in the vicinity of the surface. According to the above structure, the vertically turning flows generate the flows colliding with the mold wall surfaces in the surface of the molten metal or in the vicinity thereof. When the number of flows turning vertically is one, in one of the two opposed wall surfaces of the mold, the heat input amount into the solidified shell is increased by the flow generated in the surface of the molten metal or in the vicinity thereof and colliding with the wall surface. However, in the other of the two opposed wall surfaces of the mold, a low-temperature molten metal after transferring heat to the solidified shell in the vicinity of one wall surface flows near thereto, thereby progressing the solidification of the solidified shell. By generating in the molten metal the pair of flows turning vertically and turning in the mutually opposed directions, a pair of flows respectively colliding with the two opposed wall surfaces of the mold are generated in the surface of the molten metal or in the vicinity thereof. Thus, since the heat input amount into the solidified shell is increased in both of the two opposed wall surfaces of the mold, the progress of solidification of the solidified shell can be prevented.

[0017] In the continuous casting apparatus for a slab formed of titanium or titanium alloy according to the invention, the electromagnetic stirring device may be arranged over the whole periphery of the mold, and the electromagnetic stirring device may generate a flow moving along all wall surfaces of the mold in the molten metal. According to the above structure, by arranging the electromagnetic stirring device over the whole periphery of the mold and allowing it to generate in the molten metal the flow moving down along all wall surfaces of the mold, a flow colliding with all wall surfaces of the mold can be generated in the surface of the molten metal or in the vicinity thereof. This can increase the heat input amount into the solidified shell in the vicinity of the mold wall surfaces over the whole periphery of the mold wall surfaces.

[0018] In the continuous casting apparatus for a slab formed of titanium or titanium alloy according to the invention, the plasma arc heating device may heat the surface of the molten metal on the upstream side of the flow in the surface of the molten metal or in the vicinity of the surface. When a low-temperature molten metal flows toward the solidified shell in the vicinity of the mold wall surface, the solidification of the solidified shell is progressed. Thus, according to the above structure, by heating the surface of the molten metal on the upstream side of the flow in the surface of the molten metal or in the vicinity thereof, a high-temperature molten metal is allowed to flow toward the solidified shell in the vicinity of the mold wall surface. This can increase a heat transfer coefficient between the solidified shell and molten metal or a heat input amount into the solidified shell.

EFFECTS OF THE INVENTION

[0019] According to the continuous casting apparatus for a slab formed of titanium or titanium alloy of the invention, the surface of the molten metal charged into the mold is heated by the plasma arcs and the surface of the molten metal or the vicinity thereof is stirred electromagnetically, whereby heat is transferred to the solidified shell in the vicinity of the mold wall surface. Thus, the solidified shell in the vicinity of the mold wall surface is warmed, thereby restricting the growth of the solidified shell in the vicinity of the wall surface of the mold. Accordingly, since the occurrence of defects on the surface of the slab caused by the growth of the solidified shell in the vicinity of the mold wall surface is restricted, it is possible to cast a slab with reduced defects on its surface.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020]

Fig. 1 is a perspective view of a continuous casting apparatus.
Fig. 2 is a section view of the continuous casting apparatus shown in Fig. 1.
Figs. 3A to 3D are explanatory views of a surface defect occurring mechanism.
Figs. 4A to 4C are explanatory view sof electromagnetic stirring. Fig. 4A is a top view, Fig. 4B is a side view and Fig. 4C is a section view taken along the A-A line shown in Fig. 4B.
Figs. 5A to 5C are explanatory views of electromagnetic stirring. Fig. 5A is a top view, Fig. 5B is a side view and Fig. 5C is a section view taken along the C-C line shown in Fig. 5B.
Figs. 6A to 6C is an explanatory view of electromagnetic stirring. Fig. 6A is a top view, Fig. 6B is a side view and Fig. 6C is a section view taken along the E-E line shown in Fig. 6B.
Figs. 7A to 7C are explanatory views of electromagnetic stirring. Fig. 7A is a top view, Fig. 7B is a side view and Fig. 7C is a section view taken along the G-G line shown in Fig. 7B.
Fig. 8A is a distribution view of flow rate vector and Fig. 8B is a partially enlarged view of Fig. 8A.
Fig. 9A is a distribution view of flow rate vector and Fig. 9B is a partially enlarged view of Fig. 9A.
Figs. 10A to 10C are explanatory views of electromagnetic stirring. Fig. 10A is a top view, Fig. 10B is a side view and Fig. 10C is a section view taken along the I-I line shown in Fig. 10B.

MODES FOR CARRYING OUT THE INVENTION

[0021] Now, description is given of preferred embodiments of the invention with reference to the accompanying drawings.

[First Embodiment]

(Structure of Continuous Casting Apparatus)

[0022] A continuous casting apparatus for a slab made of titanium or titanium alloy (a continuous casting apparatus) 1 according to the present embodiment, as shown in Fig. 1, includes a mold 2, a cold hearth 3, a raw material charging device 4, plasma torches 5 and a starting block 6. Inert gas atmosphere formed of argon gas, helium gas or the like exists around the continuous casting apparatus 1.

[0023] The raw material charging device 4 charges raw material formed of titanium or titanium alloy such as sponge titanium, scrap or the like into the cold hearth 3. The plasma torches 5 are disposed above the cold hearth 3 and are used to generate plasma arcs to thereby melt the raw material within the cold hearth 3. The cold hearth 3 charges molten metal formed of molten raw material from a pouring portion 3a into the mold 2. The mold 2 is made of copper, is bottomless and has a rectangular-shaped section. The mold 2 can be cooled by water circulating inside its wall portion constituted of its four sides. The starting block 6 can be moved up and down by a drive portion (not shown) and is able to close the lower side opening of the mold 2.

[0024] The continuous casting apparatus 1, as shown in Fig. 2 as well, includes plasma torches (plasma arc heating devices) 7 and EMSs (Electro-Magnetic Stirrers) 8. The plasma torches 7 are disposed above the mold 2 and heat the surface of the molten metal 12 charged into the mold 2. The EMS 8 is of an alternating current type, while multiple EMSs 8 are disposed in the periphery of the mold 2. The EMSs 8 stir the surface of the molten metal 12 charged into the mold 2 or the vicinity of the molten metal surface by electromagnetic induction using an alternating current (stir electromagnetically). Details of the electromagnetic stirring are described later. Here, the EMS 8 also has an action to heat the molten metal 12 by electromagnetic induction.

[0025] In the above structure, the molten metal 12 charged into the mold 2 is solidified starting from its surface contacted with the mold 2 of a water cooling type. When the starting block 6 closing the lower side opening of the mold 2 is pulled downward at a given speed, a slab 11 constituted of the solidified molten metal 12 is cast continuously while being pulled down from the mold.

[0026] Here, in the case of electron beam melting in a vacuum atmosphere, it is difficult to produce titanium alloy because minute ingredients evaporate. However, in the case of plasma arc melting in an inert gas atmosphere, pure titanium and titanium alloy can be cast.

(Mechanism of occurrence of surface defects)

[0027] When the slab 11 made of titanium or titanium alloy is continuously cast, in the case that the slab 11 has irregularities or flaws on its surface, in a next process, namely, in a rolling process, the irregularities or flaws cause surface defects. Thus, the irregularities or flaws on the slab 11 surface must be removed by cutting or the like before rolling. This drops its yield rate and increases the number of operation processes, resulting in the increased cost thereof. Therefore, it is demanded that a slab 11 having no irregularities or flaws on its surface should be cast.

[0028] Here, the reason for occurrence of the flaws on the surface of the slab 11 is supposedly that the solidified shell grown excessively in the vicinity of the wall surfaces of the mold 2 is exposed to the surface of the molten metal to cover it. A mechanism for this is described using Figs. 3A to 3D. Firstly, as shown in Fig. 3A, the solidified shell 13 grows in the vicinity of the wall surfaces of the mold 2. Next, as shown in Fig. 3B, in a state where the molten metal is not supplied to the vicinity of the wall surfaces of the mold 2, the solidified shell 13 is moved downward by drawing. Then, as shown in Fig. 3C, the upper end of the solidified shell 13 becomes lower than the surface of the molten metal 12, whereby the molten metal 12 flows onto the solidified shell 13. And, as shown in Fig. 3D, the molten metal 12 having flowed onto the solidified shell 13 is solidified to provide a solidified shell 13, whereby defects are produced on the surface of the solidified shell 13. They cause the surface defects of the slab 11.

(Electromagnetic Stirring)

[0029] In this embodiment, as shown in Fig. 2, in order to restrict the occurrence of defects on the surface of the slab 11, the surface of the molten metal 12 or the vicinity thereof is stirred electromagnetically by the EMSs 8. Since plasma arcs provided by the plasma torches 7 are not influenced by a magnetic field in other portions than the vicinity of a plasma jet flow, the electromagnetic stirring is possible which is difficult in electron beam melting.

[0030] In this embodiment, as shown in Figs. 4A and 4B, the EMSs 8 are arranged three on each of the long side walls of the mold 2. Each EMS 8 is formed by winding an EMS coil on a coil iron core in the vertical direction and is able to move the molten metal 12 in the horizontal direction by electromagnetic induction.

[0031] On the upper side of Fig. 4A, the three EMSs 8a, 8a and 8a lined up on the long side walls of the mold 2 respectively move the molten metal 12 to the right in Fig. 4A. On the other hand, on the lower side of Fig. 4A, the three EMSs 8a, 8a and 8a lined up on the long side walls of the mold 2 respectively move the molten metal 12 to the left in Fig. 4A. Thus, in the surface of the molten metal 12 or in the vicinity thereof, there is generated a flow B which turns horizontally. As a result of this, in the surface of the molten metal 12 or in the vicinity thereof, there is generated a flow which moves parallel to the wall surfaces of the mold 2. Since the molten metal 12 heated by the plasma arcs is contacted with the solidified shell 13 in the vicinity of the wall surface of the mold 2, a heat transfer coefficient between the solidified shell 13 and molten metal 12 is increased. This can restrict the growth of the solidified shell 13 in the vicinity of the wall surface of the mold 2.

[0032] The plasma torches 7 are disposed to heat the surface of the molten metal 12 on the upstream side of the flow of the surface of the molten metal 12 or the vicinity thereof. Supposing the low-temperature molten metal 12 flows toward the solidified shell 13 in the vicinity of the wall surface of the mold 2, the solidification of the solidified shell 13 progresses. Thus, in this embodiment, the surface of the molten metal 12 on the upstream side of the flow of the surface of the molten metal 12 or the vicinity thereof is heated by the plasma arcs. Accordingly, the high-temperature molten metal 12 flows toward the solidified shell 13 in the vicinity of the wall surface of the mold 2, thereby properly increasing the heat transfer coefficient between the solidified shell 13 and molten metal 12.

[0033] Here, in the four corners of the rectangular-shaped mold 2, since the molten metal 12 is cooled from the two short and long sides, the molten metal 12 is easier to cool than in other portions. Also, since the four corners of the mold 2 are distant from the pouring portion 3a, the hot molten metal 12 is hard to reach. However, since the EMS 8 of an alternating current type is capable of acting power locally and thus has high controllability, it can let the high-temperature molten metal 12 flow to the four corners of the mold 2.

[0034] Also, even when heating conditions by the plasma arcs or cooling conditions by the mold 2 vary during continuous casting, by controlling the current or frequency of the EMS 8 to thereby control the speed of the electromagnetic stirring and the application position of the magnetic field, a slab 11 with no surface defects can always be cast. This applies similarly even to a case where heat inputting conditions vary greatly, as in the initial or terminal stage of the continuous casting.

(Effects)

[0035] As described above, the continuous casting apparatus 1 according to this embodiment heats the surface of the molten metal 12 poured into the mold 2 using the plasma arcs. Since the plasma arcs are not influenced by the magnetic field in other portions than the vicinity of the plasma jet flow, the electromagnetic stirring is possible which is difficult in the electron beam melting easy to be influenced by the magnetic field. Thus, by stirring the surface of the molten metal 12 or the vicinity thereof using electromagnetically, heat is transferred to the solidified shell 13 in the vicinity of the wall surface of the mold 2. Then, since the solidified shell 13 in the vicinity of the wall surface of the mold 2 is heated, the growth of the solidified shell 13 in the vicinity of the wall surface of the mold 2 is restricted. This restricts the occurrence of defects on the surface of the slab 11 caused by the growth of the solidified shell 13 in the vicinity of the wall surface of the mold 2. Therefore, a slab 11 with reduced surface defects can be cast.

[0036] Also, the arrangement of the EMSs 8 on the periphery of the mold 2 allows the stirring of the surface of the molten metal 12 or the vicinity thereof without obstructing the heating action by the plasma arcs.

[0037] Since the flow moving parallel to the wall surface of the mold 2 is generated in the surface of the molten metal 12 or the vicinity thereof, a heat transfer coefficient between the solidified shell 13 and molten metal 12 in the vicinity of the wall surface of the mold 2 can be increased. Thus, the growth of the solidified shell 13 in the vicinity of the wall surface of the mold 2 can be properly restricted.

[0038] Since the flow B turning horizontally within the mold 2 is generated in the surface of the molten metal 12 or the vicinity thereof, the flow moving parallel to the wall surface of the mold 2 can be properly generated in the surface of the molten metal 12 or in the vicinity thereof.

[0039] Also, when the low-temperature molten metal 12 flows toward the solidified shell 13 in the vicinity of the wall surface of the mold 2, the solidification of the solidified shell 13 progresses. Thus, by heating the surface of the molten metal on the upstream side of the flow of the surface of the molten metal 12 or the vicinity thereof using the plasma arcs, the high-temperature molten metal 12 is allowed to flow toward the solidified shell 13 in the vicinity of the wall surface of the mold 2. This can properly increase the heat transfer coefficient between the solidified shell 13 and molten metal 12.

[Second Embodiment]

(Electromagnetic Stirring)

[0040] Next, description is given of a continuous casting apparatus 201 according to a second embodiment of the invention. Here, the same composing elements as those described above are given the same designations and thus the description thereof is omitted. The continuous casting apparatus 201 of this embodiment is different from the continuous casting apparatus 1 of the first embodiment in that, as shown in Fig. 5A, EMSs 8 generate, in the surface of the molten metal 12 or the vicinity thereof, a pair of flows D1 and D2 respectively colliding with the two opposed short-side side wall surfaces of the mold 2.

[0041] As shown in Fig. 5A, the EMSs 8 are arranged two on each of the long side walls of the mold 2. Each EMS 8 is formed by winding an EMS coil on an iron core in the vertical direction and can move the molten metal 12 horizontally by electromagnetic induction. On the right side of Fig. 5A, the two EMSs 8a and 8a opposed to each other across the mold 2 respectively move the molten metal 12 to the right in Fig. 5A. Thus, as shown in Fig. 5A, in the surface of the molten metal 12 or in the vicinity thereof, there is generated a flow D1 which collides with the wall surface of the mold 2 constituting the right short side thereof in Fig. 5A. After colliding with the wall surface, the flow D1, as shown in Fig. 5B, moves down along the wall surface of the mold 2 constituting the right short side thereof to provide a flow D1' which turns in the vertical direction. The vertically turning flow D1' produces, in the surface of the molten metal 12 or in the vicinity thereof, a flow D1 colliding with the wall surface of the mold 2 constituting the right short side thereof in Fig. 5A.

[0042] On the left side of Fig. 5A, the two EMSs 8a and 8a opposed to each other across the mold 2 respectively move the molten metal 12 to the left in Fig. 5A. Thus, as shown in Fig. 5A, in the surface of the molten metal 12 or in the vicinity thereof, there is generated a flow D2 colliding with the wall surface of the mold 2 constituting the left short side thereof in Fig. 5A. After colliding with the wall surface, the flow D2, as shown in Fig. 5B, moves down along the wall surface of the mold 2 constituting the left short side thereof in Fig. 5A to provide a flow D2' which turns vertically. The vertically turning flow D2' produces, in the surface of the molten titanium 12 or in the vicinity thereof, a flow D2 colliding with the wall surface of the mold 2 constituting the left short side thereof in Fig. 5A.

[0043] The pair of flows D1 and D2, which exist in the surface of the molten metal 12 or in the vicinity thereof and respectively collide with the two opposed short side wall surfaces of the mold 2, increase the amount of heat input into the solidified shell 13 in the vicinity of the short side wall surfaces of the mold 2. This restricts the growth of the solidified shell 13 in the vicinity of the short side wall surfaces of the mold 2.

[0044] Also, the pair of flows D1 and D2 respectively colliding with the two opposed short side wall surfaces of the mold 2 generate in the molten metal 12 a pair of flows D1' and D2' which turn in the vertical direction and also turns in the mutually opposing directions. And, the pair of vertically turning flows D1' and D2' generate, in the surface of the molten metal 12 or in the vicinity thereof, the pair of flows D1 and D2 respectively colliding with the two opposed short side wall surfaces of the mold 2. Here, when the number of flows turning vertically is one, in one of the two short side wall surfaces, the flow generated in the surface of the molten metal 12 or in the vicinity thereof and colliding with the wall surface increases the heat input amount into the solidified shell 13. However, in the vicinity of the other of the two short side wall surfaces, there flows a low-temperature molten metal 12 after transferring the heat to the solidified shell 13 in the vicinity of one of the wall surfaces, which progresses the solidification of the solidified shell 13. Thus, by generating in the molten metal 12 the pair of flows D1' and D2' turning vertically in the mutually opposing directions, the pair of flows D1 and D2 respectively colliding with the two opposed wall surfaces of the mold 2 are generated in the surface of the molten metal or in the vicinity thereof. This increases the amount of heat input into the solidified shell 13 in each of the two opposed short side wall surfaces of the mold 2, thereby preventing the progress of the solidification of the solidified shell 13.

[0045] Also, the plasma torches 7 are arranged to heat the surface of the molten metal 12 on the upstream side of the flow of the surface of the molten metal or in the vicinity thereof. Thus, a high-temperature molten metal 12 flows toward the solidified shell 13 in the vicinity of the short side wall surface of the mold 2, thereby increasing properly the amount of heat input into the solidified shell 13 in the vicinity of the short side wall surfaces of the mold 2.

[0046] Here, the pair of flows D1 and D2 respectively colliding with the short side wall surfaces of the mold 2 include flows moving parallel to the long side wall surfaces of the mold 2. Therefore, in the long side wall surfaces of the mold 2, the heat transfer coefficient between the solidified shell 13 and molten titanium 12 increases. This restricts the growth of the solidified shell 13 in the vicinity of the long side wall surfaces of the mold 2.

(Effects)

[0047] As described above, according to the continuous casting apparatus 201 of this embodiment, since the flows D1 and D2 colliding with the short side wall surfaces of the mold 2 are generated in the surface of the molten metal 12 or in the vicinity thereof, the amount of heat input into the solidified shell 13 in the vicinity of the short side wall surfaces of the mold 2 can be increased. This can properly restrict the growth of the solidified shell 13 in the vicinity of the short side wall surfaces of the mold 2.

[0048] Also, the vertically turning flows D1' and D2' generate, in the surface of the molten titanium 12 or in the vicinity thereof, the flows D1 and D2 colliding with the wall surfaces of the mold 2. When the number of flows turning vertically is one, in one of the two opposed short side wall surfaces of the mold 2, the amount of heat input into the solidified shell 13 is increased by the flow generated in the surface of the molten metal 12 or in the vicinity thereof and colliding with the wall surface. However, in the vicinity of the other of the two opposed short side wall surfaces of the mold 2, there flows a low-temperature molten metal 12 after transferring its heat to the solidified shell 13 in the vicinity of the one wall surface, thereby progressing the solidification of the solidified shell 13. Thus, by generating in the molten metal 12 the pair of flows D1' and D2' turning vertically in the opposed directions, the pair of flows D1 and D2 respectively colliding with the two opposed short side wall surfaces of the mold 2 are generated in the surface of the molten metal 12 or in the vicinity thereof. This increases the amount of heat input into the solidified shell 13 in both of the two opposed short side wall surfaces of the mold 2, thereby preventing the progress of the solidification of the solidified shell 13.

[Third Embodiment]

(Electromagnetic Stirring)

[0049] Next, description is given of a continuous casting apparatus 301 according to a third embodiment of the invention. Here, the same composing elements as those described above are given the same designations and thus the description thereof is omitted. In the continuous casting apparatus 301 of this embodiment, as shown in Figs. 6A and 6B, EMSs 8 are arranged apiece on each side of the two short side wall surfaces of the mold 2. Thus, the continuous casting apparatus 301 of this embodiment is different from the continuous casting apparatus 201 of the second embodiment in that a flow moving down along the wall surfaces of the short side wall surfaces of the mold 2 is generated in the molten metal 12.

[0050] The EMS 8 is formed by winding an EMS coil on a coil iron core horizontally and moves the molten titanium 12 downward in the vertical direction by electromagnetic induction. The EMS 8a disposed on the right in Fig. 6B generates in the molten metal 12 a flow moving down along the wall surface of the mold 2 constituting the right short side thereof in Fig. 6B. Also, the EMS 8b disposed on the left in Fig. 6B generates in the molten metal 12 a flow moving down along the wall surface of the mold 2 constituting the left short side thereof in Fig. 6B of the mold 2. These flows, as shown in Fig. 6B, turn vertically and generate a pair of flows F1' and F2' which turn vertically in the mutually opposing directions.

[0051] As shown in Fig. 6B, the flow F1', in the surface of the molten metal 12 or in the vicinity thereof, generates a flow which collides with the wall surface of the mold 2 constituting the right short side thereof in Fig. 6B. Therefore, as shown in Fig. 6A, in the surface of the molten metal 12 or in the vicinity thereof, there is generated a flow F1 which collides with the wall surface of the mold 2 constituting the right short side thereof in Fig. 6A. Also, as shown in Fig. 6B, a flow F2' is a flow which turns in the opposite direction to the flow F1' and which also generates, in the surface of the molten metal 12 or in the vicinity thereof, a flow colliding with the wall surface of the mold 2 constituting the left short side thereof in Fig. 6B. Thus, as shown in Fig. 6A, in the surface of the molten metal 12 or in the vicinity thereof, there is generated a flow F2 which collides with the wall surface of the mold 2 constituting the left short side thereof in Fig. 6A.

[0052] The pair of flows F1 and F2 respectively colliding with the two wall surfaces of the mold 2 constituting the short sides thereof in the surface of the molten metal 12 or in the vicinity thereof increase the amount of heat input into the solidified shell 13 in the vicinity of the short side wall surfaces of the mold 2, thereby restricting the growth of the solidified shell 13 in the vicinity of the short side wall surfaces of the mold 2.

[0053] The plasma torches 7 are disposed to heat the surface of the molten metal 12 on the upstream side of the flow in the surface of the molten metal 12 or in the vicinity thereof. Thus, a high-temperature molten metal 12 flows toward the solidified shell 13 in the vicinity of the short side wall surfaces of the mold 2, thereby increasing the amount of heat input into the solidified shell 13 in the vicinity of the short side wall surfaces of the mold 2.

(Effects)

[0054] As described above, according to the continuous casting apparatus 301 of this embodiment, by generating in the molten metal 12 the flows moving down along the short side wall surfaces of the mold 2, there are generated in the molten metal 12 the flows F1' and F2' respectively turning in the vertical direction. These vertically turning flows F1' and F2' can properly generate, in the surface of the molten metal 12 or in the vicinity thereof, the flows F1 and F2 which collide with the wall surfaces of the mold 2.

[Fourth Embodiment]

(Electromagnetic Stirring)

[0055] Next, description is given of a continuous casting apparatus 401 according to a fourth embodiment of the invention. Here, the same composing elements as those described above are given the same designations and thus the description thereof is omitted. The continuous casting apparatus 401 of this embodiment is different from the continuous casting apparatus 301 of the third embodiment in that, as shown in Figs. 7A and 7B, EMSs 8 generate flows moving down along the long side wall surfaces of the mold 2.

[0056] As shown in Fig. 7A, the EMSs 8 are arranged two on each side of the long side wall surfaces of the mold 2. Each of these EMSs 8 is formed by winding an EMS coil on a coil iron core horizontally. The EMS 8 causes the molten metal 12 to flow down vertically by electromagnetic induction. On the right in Fig. 7C, two EMSs 8a and 8a lined up on the long side of the mold 2 respectively generate, in the molten metal 12, flows moving down along the right long side wall surface of the mold 2. Also, on the left in Fig. 7C, two EMSs 8b and 8b lined up on the long side of the mold 2 respectively generate, in the molten metal 12, flows moving down along the left long side wall surface of the mold 2. These flows, as shown in Fig. 7C, generate a pair of flows H1' and H2' which turn vertically and also turn in the mutually opposing directions.

[0057] As shown in Fig. 7C, the flow H1' generates, in the surface of the molten metal 12 or in the vicinity thereof, a flow which collides with wall surface of the mold 2 constituting the right long side thereof in Fig. 7C. Therefore, as shown in Fig. 7A, in the surface of the molten metal 12 or in the vicinity thereof, there is generated a flow H1 which collides with the side wall surface of the mold 2 constituting the upper long side thereof in Fig. 7A. Also, as shown in Fig. 7C, a flow H2' is a flow which turns in the opposite direction to the flow H1' and also which, in the surface of the molten metal 12 or in the vicinity thereof, generates a flow colliding with the side wall surface of the mold 2 constituting the left long side thereof in Fig. 7C. Therefore, as shown in Fig. 7A, in the surface of the molten metal 12 or in the vicinity thereof, there is generated a flow H2 which collides with the side wall surface of the mold 2 constituting the lower long side thereof in Fig. 7A.

[0058] The pair of flows H1 and H2 respectively generated in the surface of the molten metal 12 or in the vicinity thereof and colliding with the two long side wall surfaces of the mold 2 increase the amount of heat input into the solidified shell 13 in the vicinity of the long side wall surfaces of the mold 2. Thus, in the vicinity of the long side wall surfaces of the mold 2, the growth of the solidified shell 13 is restricted.

[0059] The plasma torches 7 are disposed to heat the surface of the molten metal 12 on the upstream side of the flow in the surface of the molten metal 12 or in the vicinity thereof. Thus, a high-temperature molten metal 12 flows toward the solidified shell 13 in the vicinity of the long side wall surfaces of the mold 2, thereby increasing properly the amount of heat input into the solidified shell 13 in the vicinity of the long side wall surfaces of the mold 2.

(Comparison of Stirring Conditions)

[0060] Here, using flow rate vector distribution views shown in Figs. 8A, 8B, 9A and 9B, description is given of the stirring condition of the molten metal 12 in the continuous casting apparatus 401 of this embodiment in comparison with a comparison example providing an opposite stirring direction. In the continuous casting apparatus 401 of this embodiment, as shown in Fig. 8A, by generating in the molten metal 12 the pair of flows turning vertically in the mutually opposite directions, there are generated, in the surface of the molten metal 12 or in the vicinity thereof, the pair of flows which respectively collide with the two long side wall surfaces of the mold 2. As can be seen also from Fig. 8B which is a partially enlarged view of Fig. 8A, a high-temperature molten metal 12 flows toward the solidified shell 13 in the vicinity of the long side wall surfaces of the mold 2. This increases the amount of heat input into the solidified shell 13 in the vicinity of the long side wall surfaces of the mold 2, thereby restricting the progress of the solidification of the solidified shell 13.

[0061] On the other hand, in the comparison example, as shown in Fig. 9A, there are generated a pair of flows which turn vertically in the mutually opposite directions. However, in the comparison example, reversely to the continuous casting apparatus 401 of this embodiment, a pair of flows moving from the two respective long side wall surfaces of the mold 2 toward the center thereof are generated in the surface of the molten metal 12 or in the vicinity thereof. As can be seen also from Fig. 9B which is a partially enlarged view of Fig. 9A, a low temperature-molten metal 12 flows toward the solidified shell 13 in the vicinity of the long side wall surfaces of the mold 2. This decreases the amount of heat input into the solidified shell 13 in the vicinity of the long side wall surfaces of the mold 2, which promotes the progress of the solidification of the solidified shell 13.

[0062] Thus, in order to generate in the molten metal 12 a pair of flows which turn vertically in the mutually opposite directions, as in this embodiment, it is effective that a pair of flows respectively colliding with the two opposed long side surfaces of the mold 2 are generated in the surface of the molten metal 12 or in the vicinity thereof. Therefore, in order to prevent the progress of the solidification of the solidified shell 13, this embodiment is more effective than the comparison example in which the pair of flows respectively moving from the two long side wall surfaces of the mold 2 toward the center thereof are generated in the surface of the molten metal 12 or in the vicinity thereof. This also applies similarly to the second and third embodiments.

[Fifth Embodiment]

(Electromagnetic Stirring)

[0063] Next, description is given of a continuous casting apparatus 501 according to a fifth embodiment of the invention.

[0064] Here, the same composing elements as those described above are given the same designations and thus the description thereof is omitted. The continuous casting apparatus 501 of this embodiment is different from the continuous casting apparatus 1 of the first embodiment in that, as shown in Figs. 10A to 10C, EMSs 508 are arranged over the whole periphery of the mold 2 and generate flows moving down along all wall surfaces of the mold 2.

[0065] Each EMS 508 is formed by winding an EMS coil on a coil iron core horizontally and moves the molten metal 12 downward in the vertical direction by electromagnetic induction. This generates in the molten metal 12 a flow which moves down along all wall surfaces of the mold 2, while this flow generates a flow turning vertically. This vertically turning flow face in all directions and thus, as shown in Fig. 8A, in the surface of the molten metal 12 or in the vicinity thereof, there is generated a flow J which collides with all wall surfaces of the mold 2. This increases the amount of heat input into the solidified shell 13 over the whole periphery of the wall surfaces of the mold 2.

[0066] Also, the plasma torches 7 are disposed to heat the surface of the molten metal 12 on the upstream side of the flow in the surface of the molten metal 12 or in the vicinity thereof. Thus, a high-temperature molten metal 12 flows toward the solidified shell 13 in the vicinity of the wall surfaces of the mold 2, thereby increasing properly the amount of heat input into the solidified shell 13 in the vicinity of the wall surfaces of the mold 2.

(Effects)

[0067] As described above, in the continuous casting apparatus 501 of this embodiment, the EMSs 508 are arranged over the whole periphery of the mold 2. Thus, according to continuous casting apparatus 501 of this embodiment, by generating in the molten metal the flow moving down along all wall surfaces of the mold 2, the flow J colliding with all wall surfaces of the mold 2 can be generated in the surface of the molten metal 12 or in the vicinity thereof. This can increase the amount of heat input into the solidified shell 13 in the vicinity of the wall surfaces of the mold 2 over the whole periphery of the wall surfaces of the mold 2.

(Modification)

[0068] Although description has been given heretofore of the embodiments of the invention, they are just the specific examples of the invention but do not limit the invention specifically. The specific structures can be changed properly in design. Also, the operations and effects described in the embodiments of the invention are just the most preferred ones that can be produced from the invention. The operations and effects obtainable from the invention are not limited to those described in the embodiments of the invention.

[0069] For example, a flux charging device for charging flux onto the surface of the molten metal 12 may also be provided. The lubricating effect of the flux inserted between the mold 2 and solidified shell 13 can restrict further the occurrence of defects on the surface of the slab 11.

[0070] This application is based on Japanese Patent Application No. 2011-192062 filed on September 2, 2011, and thus the contents thereof are incorporated herein for reference.

EXPLANATIONS OF LETTERS AND NUMERALS

[0071]

1, 201, 301, 401, 501: continuous casting apparatus
2: mold
3: cold hearth
3a: pouring portion
4: raw material charging device
5: plasma torch
6: starting block
7: plasma torch (plasma arc heating device)
8: EMS (electromagnetic stirring device)
11: slab
12: molten metal
13: solidified shell

Claims

1. A continuous casting apparatus for charging molten metal constituted of molten titanium or titanium alloy into a bottomless rectangular-shaped mold, solidifying the molten metal therein and drawing out the solidified molten metal, thereby continuously casting a slab formed of titanium or titanium alloy, the continuous casting apparatus comprising:

a plasma arc heating device configured to heat

the surface of the molten metal charged into the mold using plasma arcs; and
at least one electromagnetic stirring device configured to stir the surface of the molten metal or the vicinity of the surface by electromagnetic induction using an alternating current.

2. A continuous casting apparatus for a slab formed of titanium or titanium alloy according to Claim 1, wherein
the electromagnetic stirring device is arranged on a periphery of the mold.

3. A continuous casting apparatus for a slab formed of titanium or titanium alloy according to Claim 1 or 2, wherein
the electromagnetic stirring device generates a flow moving parallel to the wall surface of the mold in the surface of the molten metal or in the vicinity of the surface.

4. A continuous casting apparatus for a slab formed of titanium or titanium alloy according to Claim 3, wherein
the electromagnetic stirring device generates a flow turning in the horizontal direction in the surface of the molten metal or in the vicinity of the surface.

5. A continuous casting apparatus for a slab formed of titanium or titanium alloy according to Claim 1 or 2, wherein
the electromagnetic stirring device generates a flow colliding with the wall surface of the mold in the surface of the molten metal or in the vicinity of the surface.

6. A continuous casting apparatus for a slab formed of titanium or titanium alloy according to Claim 5, wherein
the electromagnetic stirring device generates a flow moving down along the wall surface of the mold in the molten metal.

7. A continuous casting apparatus for a slab formed of titanium or titanium alloy according to Claim 5, wherein
the electromagnetic stirring device generates a pair of flows turning in the vertical direction and also turning in the mutually opposite directions in the molten metal, to thereby generate a pair of flows respectively colliding with the two opposed wall surfaces of the mold in the surface of the molten metal or in the vicinity of the surface.

8. A continuous casting apparatus for a slab formed of titanium or titanium alloy according to Claim 6, wherein:
the electromagnetic stirring device is arranged over the whole periphery of the mold; and
the electromagnetic stirring device generates a flow moving along all wall surfaces of the mold in the molten metal.

9. A continuous casting apparatus for a slab formed of titanium or titanium alloy according to Claim 3, wherein
the plasma arc heating device heats the surface of the molten metal on the upstream side of the flow in the surface of the molten metal or in the vicinity of the surface.

10. A continuous casting apparatus for a slab formed of titanium or titanium alloy according to Claim 5, wherein
the plasma arc heating device heats the surface of the molten metal on the upstream side of the flow in the surface of the molten metal or in the vicinity of the surface.

FIG. 1

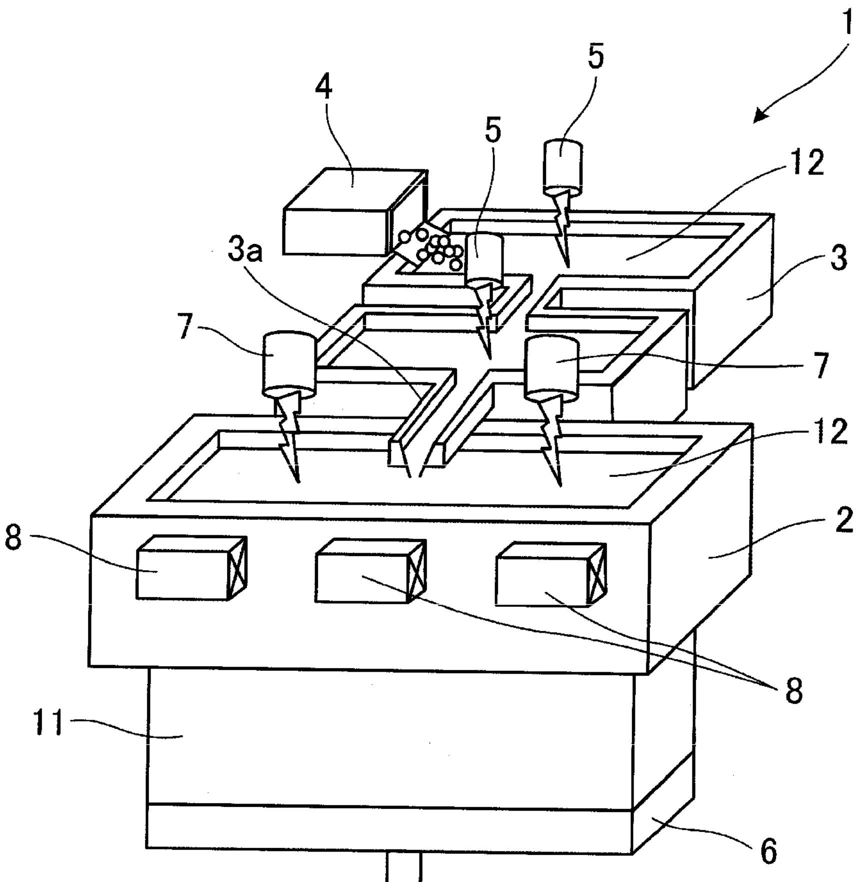

FIG. 2

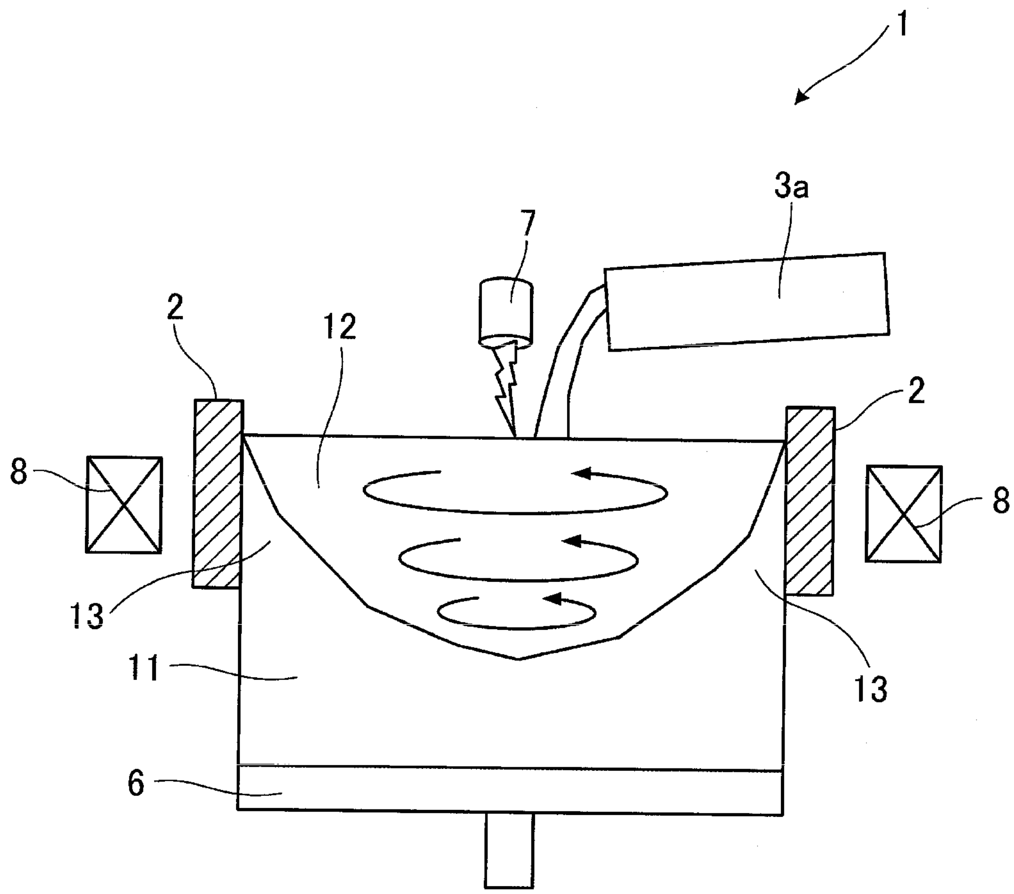

FIG. 3A

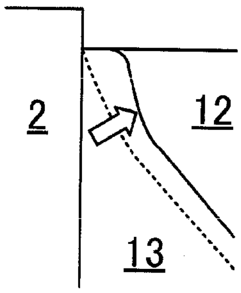

FIG. 3B

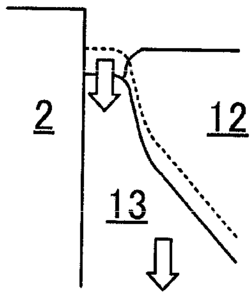

FIG. 3C

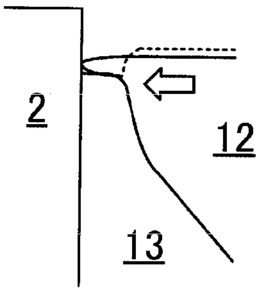

FIG. 3D

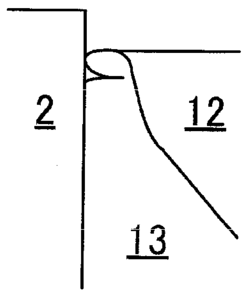

FIG. 4A

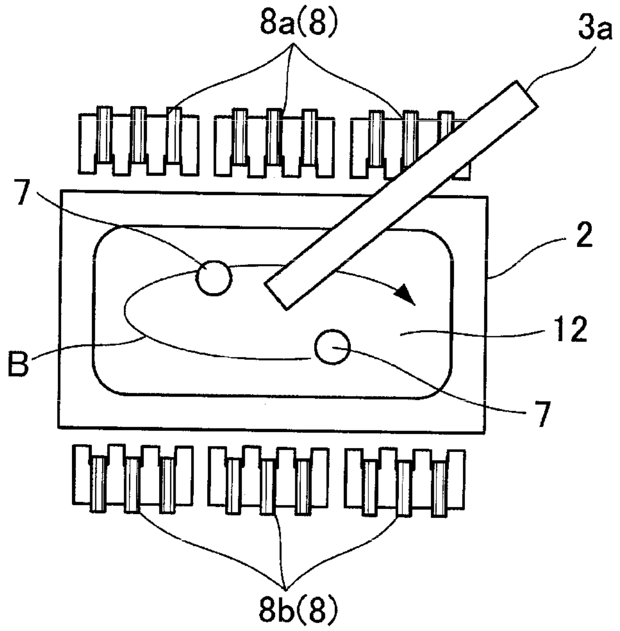

FIG. 4B

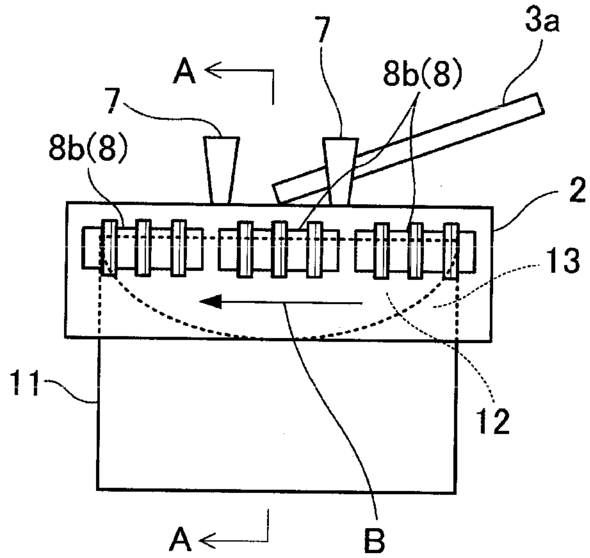

FIG. 4C

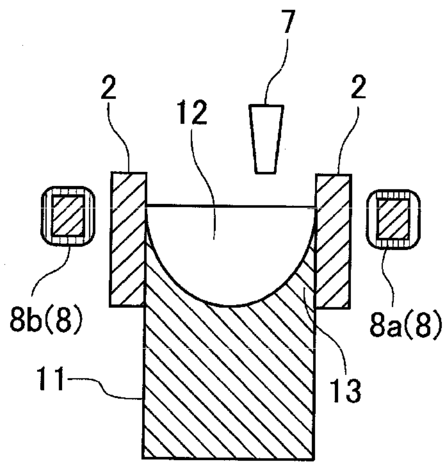

FIG. 5A

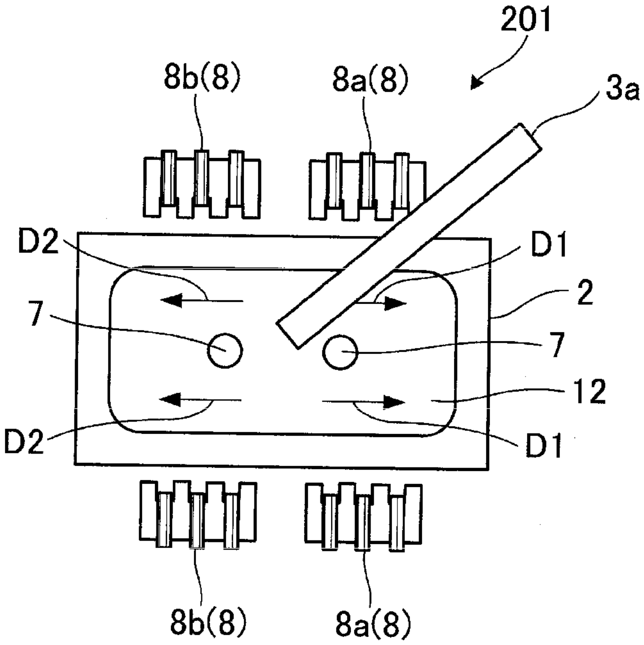

FIG. 5B

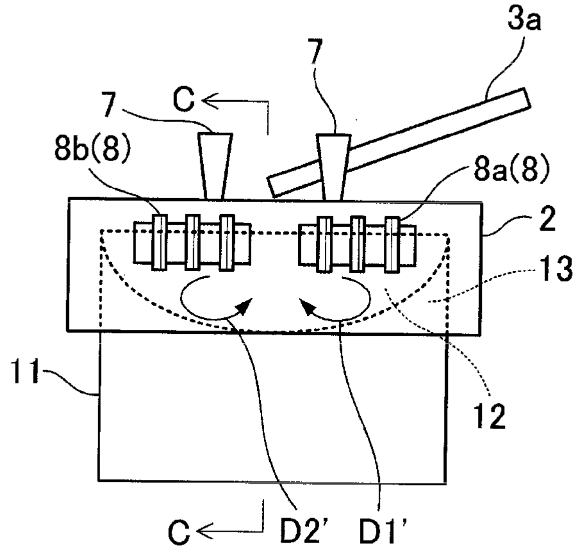

FIG. 5C

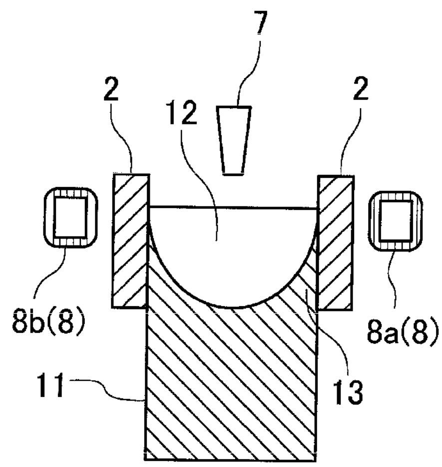

FIG. 6A

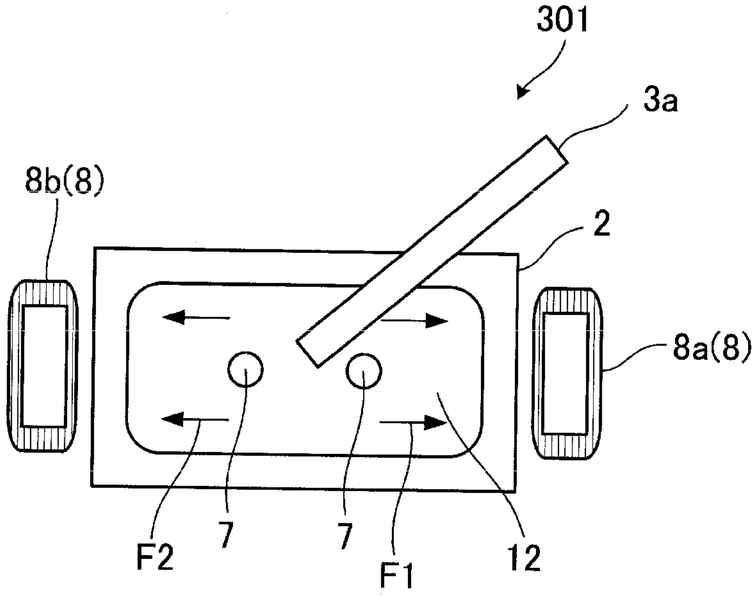

FIG. 6B

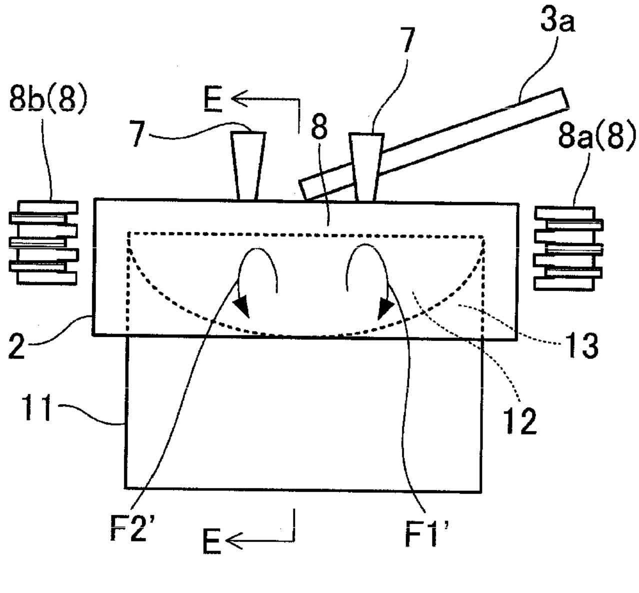

FIG. 6C

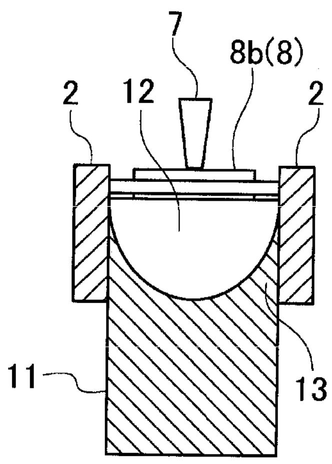

FIG. 7A

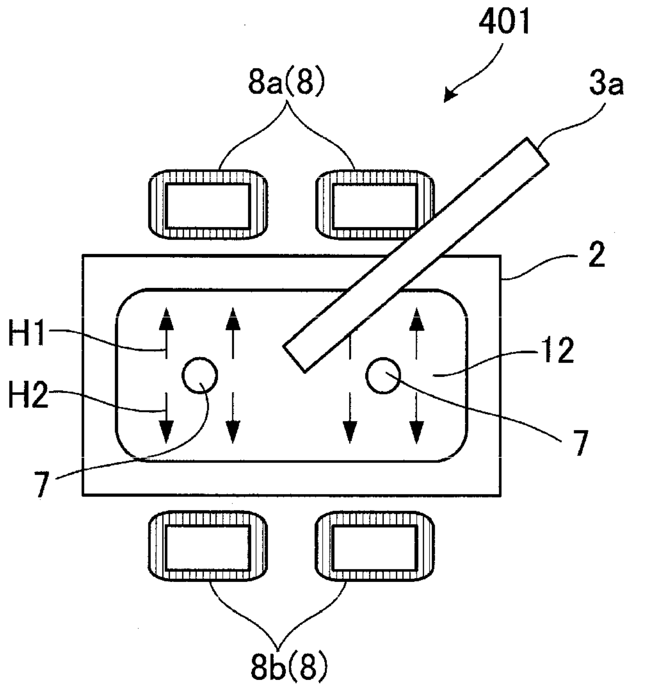

FIG. 7B

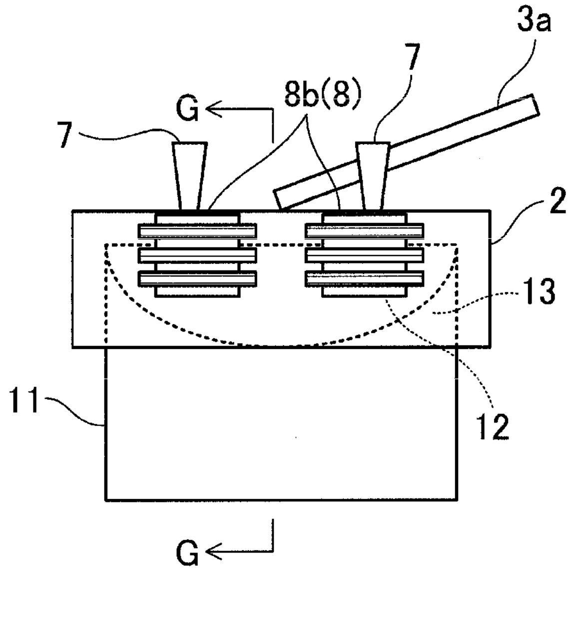

FIG. 7C

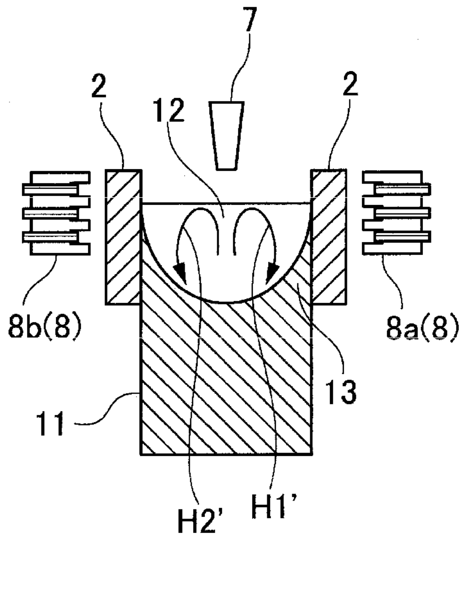

FIG. 8A

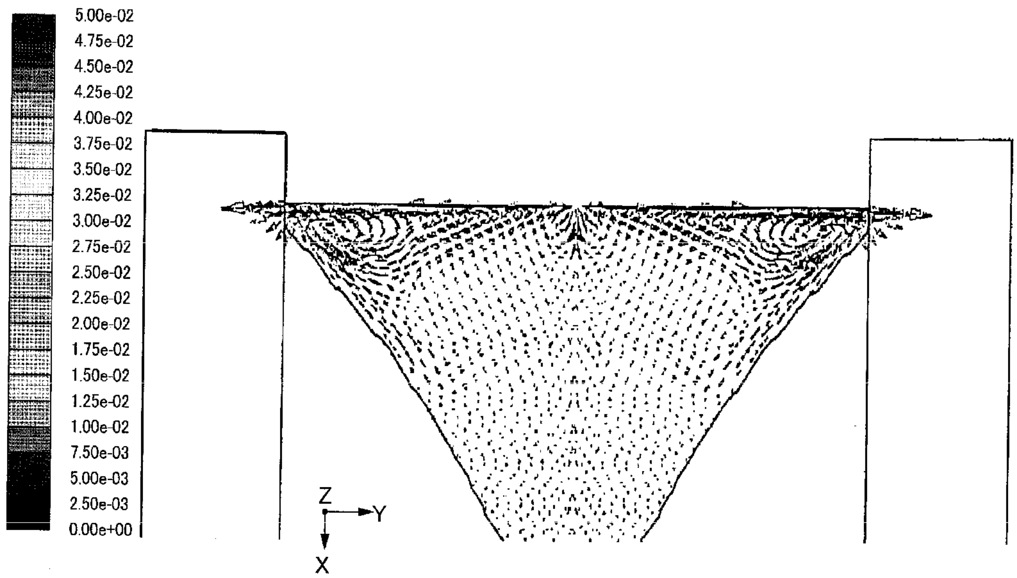
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FIG. 8B

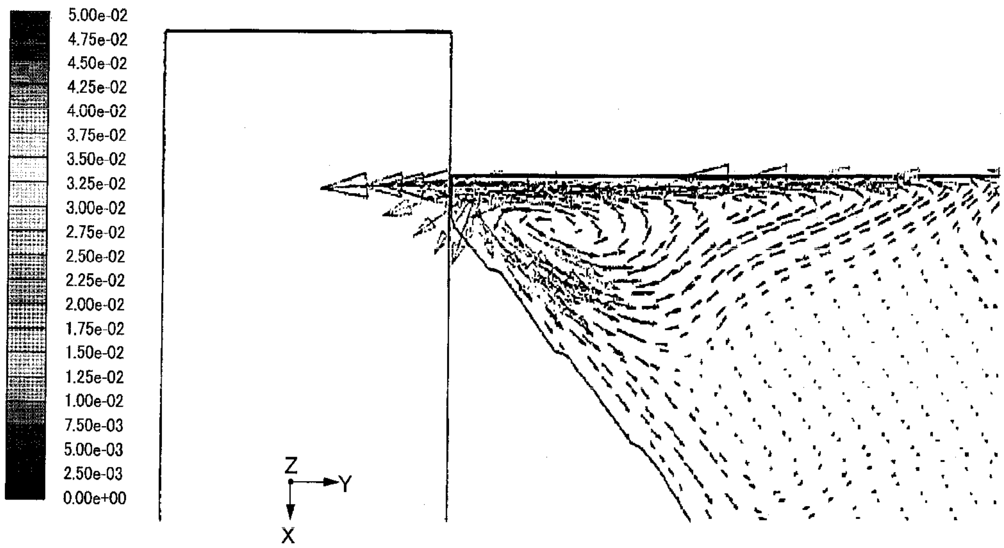
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FIG. 9A

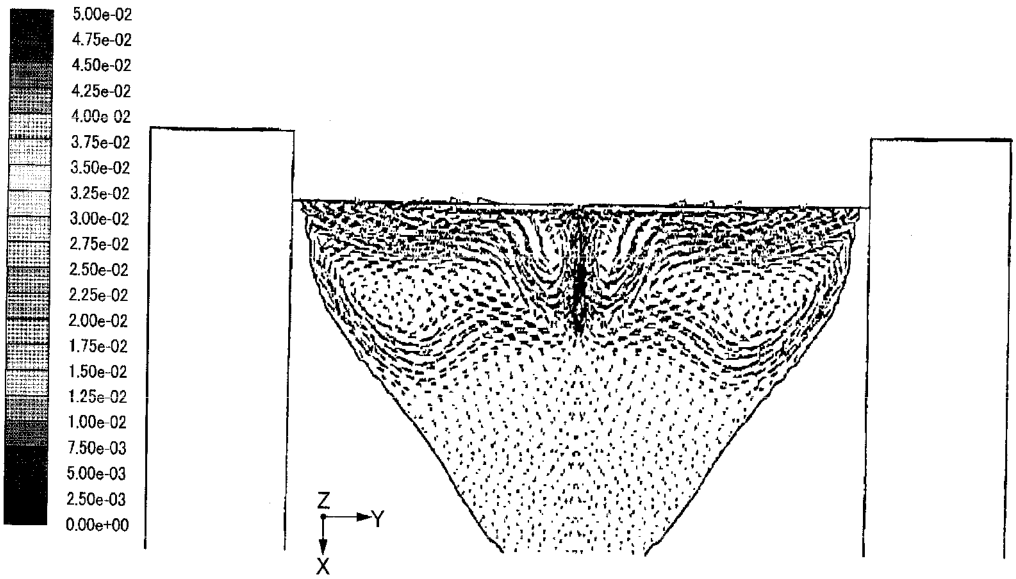
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FIG. 9B

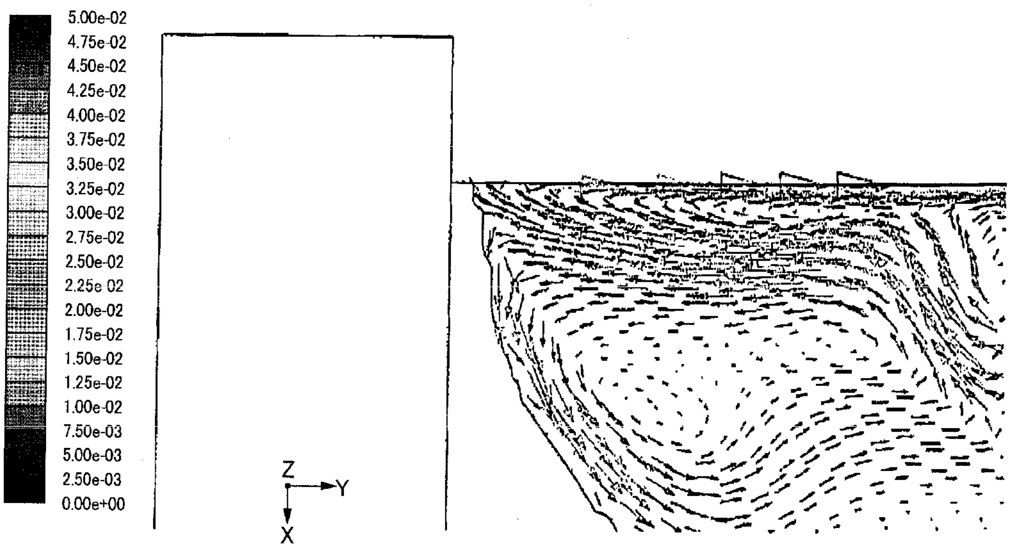
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FIG. 10A

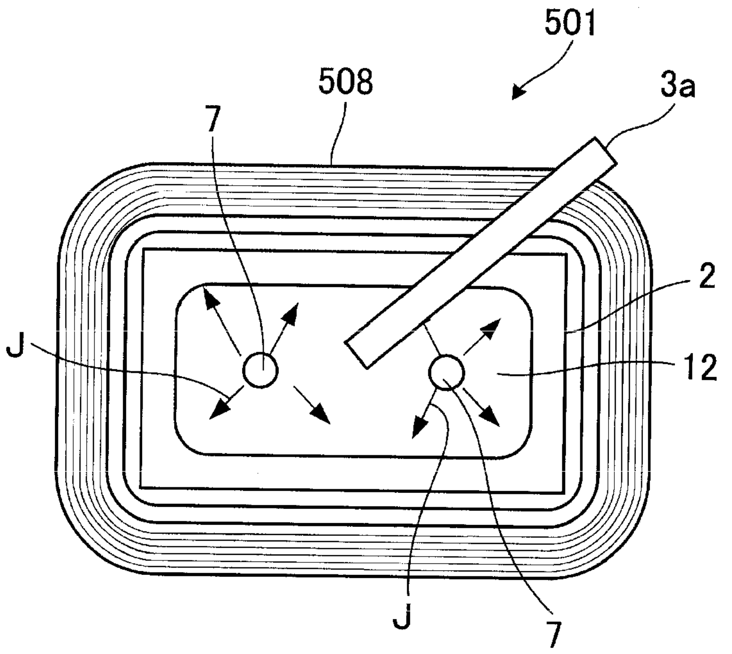


FIG. 10B

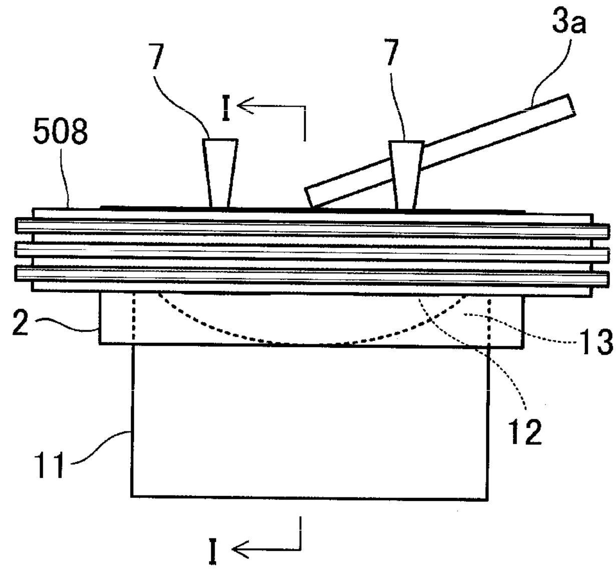
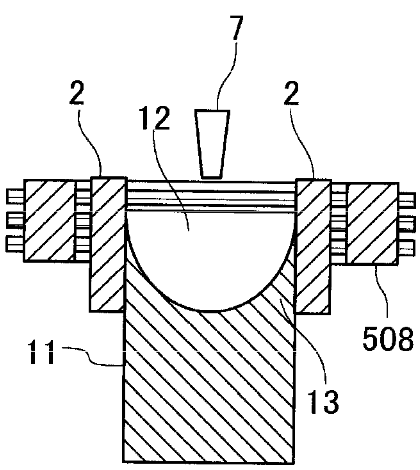


FIG. 10C



INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2012/068635

A. CLASSIFICATION OF SUBJECT MATTER
B22D11/00(2006.01)i, *B22D11/11*(2006.01)i, *B22D11/115*(2006.01)i, *B22D27/02*(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B22D11/00, B22D11/11, B22D11/115, B22D27/02

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2012
Kokai Jitsuyo Shinan Koho	1971-2012	Toroku Jitsuyo Shinan Koho	1994-2012

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	JP 4704797 B2 (Kobe Steel, Ltd.), 18 March 2011 (18.03.2011), claims; paragraph [0018] & JP 2006-299302 A	1-6,8-10 7
Y A	JP 6-313685 A (Nippon Steel Corp.), 08 November 1994 (08.11.1994), claims; paragraphs [0002], [0018] (Family: none)	1-6,8-10 7

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 September, 2012 (28.09.12)	16 October, 2012 (16.10.12)

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

Form PCT/ISA/210 (second sheet) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2004136368 A **[0004]**
- JP 2011192062 A **[0070]**