(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 158 985 A1

(12) EUROPEAN PATENT APPLICATION
published in accordance with Art. 153(4) EPC

(43) Date of publication:
03.03.2010 Bulletin 2010/09

(21) Application number: **08740581.7**

(22) Date of filing: **17.04.2008**

(51) Int Cl.:
B22D 11/115 (2006.01) ***B22D 11/04*** (2006.01)
B22D 11/11 (2006.01) ***B22D 11/18*** (2006.01)

(86) International application number:
PCT/JP2008/057511

(87) International publication number:
WO 2009/001609 (31.12.2008 Gazette 2009/01)

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MT NL NO PL PT RO SE SI SK TR
Designated Extension States:
AL BA MK RS

(30) Priority: **28.06.2007 JP 2007170578**

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(54) CONTINUOUS CASTING METHOD OF STEEL

(57) PROBLEM:

To specify a mode for applying current to a dual-purpose coil.

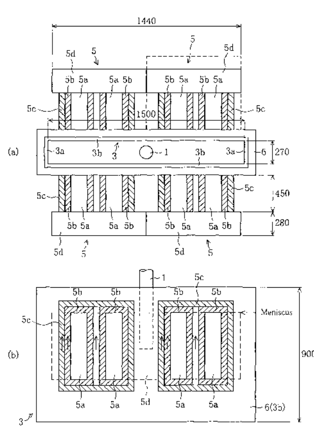
MEANS:

Arranging two first excitation coils 5b wound around respective outer peripheries of two magnetic polar iron cores 5a, and a second electromagnetic coil having one excitation coil 5c wound around the outer periphery of the two magnetic polar iron cores 5a together, in the same number on the outer periphery of a wide side 3b of a mold 3, for a total of (2n + 2) on the outer periphery (n is a natural number) of the wide side 3b. In the case of electromagnetic stirring, a multi-phase alternating current of 3 phases or more, each phase having a phase difference from 90° to 120°, is applied to the excitation coils 5b, 5c of all of the electromagnetic coils, in the case of electromagnetic stirring. In the case of electromagnetic braking, a direct current is applied to the excitation coil 5c or to the 3 excitation coils 5b, 5c for each of the first and second electromagnetic coils. Electromagnetic braking or electromagnetic stirring is selectively activated according to the composition of the molten steel and the amount of molten steel 2 supplied.

ADVANTAGEOUS EFFECTS:

It is possible to stably produce cast slabs with good surface quality, regardless of the type of steel and casting conditions, and the occurrence of break-out can be controlled, thereby making it possible to achieve a stable casting operation.

Figure 1



EP 2 158 985 A1

Printed by Jouve, 75001 PARIS (FR)

Description

TECHNICAL FIELD

[0001] The present invention relates to a method of continuous casting of steel that employs an electromagnetic coil capable of selectively activating electromagnetic braking or electromagnetic stirring, while controlling the flow of in-mold molten steel.

BACKGROUND ART

[0002] In typical continuous casting of steel, molten steel is injected into a mold by using an immersion nozzle with two outlet ports. FIG. 2 is a schematic sectional view of a fluid state of molten steel within a mold in this typical continuous casting. Molten steel 2, which is discharged from a outlet port 1a of an immersion nozzle 1, collides against a solidifying shell 2c on a narrow side 3a of a mold 3. After contact with the solidifying shell 2c on the narrow side 3a, the molten steel separates into an upward flow 2a and a downward flow 2b. The upward flow 2a then forms a horizontal flow below the meniscus and moves in the direction of the immersion nozzle 1. Reference Numeral 4 in FIG. 2 shows a mold powder.

[0003] Control of the flow of molten steel in the mold is of the utmost importance in the operation and quality control of cast slabs. There are various methods for achieving flow control of molten steel, such as improving the shape of the immersion nozzle, or applying an electromagnetic force to the molten steel in the mold. In recent years, methods of applying an electromagnetic force to the molten steel have come to be widely used. There are two methods of applying an electromagnetic force to the molten steel: using an electromagnetic brake to apply a braking force to the molten steel flow discharged from the immersion nozzle, and using electromagnetic stirring to stir the molten steel by means of an electromagnetic force.

[0004] Electromagnetic braking and electromagnetic stirring each have their advantages and disadvantages, but generally speaking, electromagnetic braking is used in high-speed casting, and electromagnetic stirring is used in low-speed casting. Electromagnetic brakes and electromagnetic stirrers are both equipped with an electromagnetic core which has an iron core wound with a coil. The iron core is typically disposed at the back side of a copper plate of a mold. Devices which have these electromagnetic coils typically have a single function, either electromagnetic braking or electromagnetic stirring.

[0005] Accordingly, for some time now, electromagnetic coil devices have been developed with the capability of functioning both as an electromagnetic brake and as an electromagnetic stirrer (referred to below as a dual-purpose coil), as disclosed by the applicant in Patent References 1 and 2.

Patent Reference 1: Japanese Patent Application Kokai Publication No. 2005-349454
Patent Reference 2: Japanese Patent Application Kokai Publication No. 2007-007719

[0006] The dual-purpose coil of Patent References 1 and 2 selectively causes electromagnetic braking or electromagnetic stirring to act on molten steel in a mold, by supplying direct or alternating current to an electromagnetic coil disposed on the outer periphery of the mold.

[0007] The dual-purpose coil disclosed in Patent References 1 and 2 enables the use of both electromagnetic braking and electromagnetic stirring, which was heretofore impossible.

DISCLOSURE OF THE INVENTION

PROBLEM TO BE SOLVED BY THE INVENTION

[0008] The problem to be solved by the present invention is that in the case of a dual-purpose coil capable of functioning both as an electromagnetic brake and as an electromagnetic stirrer, it was not clear how to apply electrical current during continuous casting of steel, as disclosed by the applicant.

MEANS FOR SOLVING THESE PROBLEMS

[0009] The method of continuous casting of steel according to an embodiment of the present invention is a method that specifies a mode for applying current to a dual-purpose coil. The method may include the acts of:

arranging at least two polar iron cores in the same number on the outer periphery of a wide side of a mold, for a total of (2n + 2) on the outer periphery of the wide side of the mold, wherein n is a natural number, wherein each of the polar iron cores comprises a first excitation coil wound around outer periphery of the magnetic polar iron core, and wherein a second excitation coil is wound around the outer periphery of two of the at least two magnetic polar iron cores, such that the two magnetic polar iron cores are wound together;

applying, in the case of electromagnetic stirring, a multi-phase alternating current to the excitation coils of all of the electromagnetic coils, wherein the multi-phase alternating current has at least 3 phases, each phase having a phase difference from between about 90° to about 120°;

applying, in the case of electromagnetic braking, a direct current to the second excitation coil or to the first excitation coils wound around the two magnetic polar iron cores and the second excitation coil, and

selectively activating the electromagnetic braking or the electromagnetic stirring according to the composition of the molten steel and the amount of molten steel supplied.

[0010] In one aspect, when the constituent carbon concentration of the molten steel supplied to the mold is at least 0.07% and 0.16% or less in terms of mass percentage:

1) a multi-phase alternating current of 3 phases or more is applied to the first and second electromagnetic coils, thereby causing electromagnetic stirring to act on molten steel disposed in the mold, when the molten steel is supplied at less than 3 ton/min, and

2) a direct current is applied to the first and second electromagnetic coils in order to cause electromagnetic braking to act on molten steel disposed in the mold, when the molten steel is supplied at 3 ton/min or more.

[0011] In another aspect, when the constituent carbon concentration of the molten steel supplied to the mold is greater than 0.0050% and less than 0.07% in terms of mass percentage:

1)a multi-phase alternating current of 3 phases or more is applied to the first and second electromagnetic coils in order to cause electromagnetic stirring to act on molten steel disposed in the mold, when the molten steel is supplied at less than 4 ton/min, and

2) a direct current is applied to the first and second electromagnetic coils in order to cause electromagnetic braking to act on molten steel disposed in the mold, when the molten steel is supplied at 4 ton/min or more.

[0012] In yet another aspect, when the constituent carbon concentration of the molten steel supplied to the mold is 0.0050% or less in terms of mass percentage:

1) a multi-phase alternating current of 3 phases or more is applied to the first and second electromagnetic coils in order to cause electromagnetic stirring to act on molten steel disposed in the mold, when the molten steel is supplied at less than 5 ton/min, and

2) a direct current is applied to the first and second electromagnetic coils in order to cause electromagnetic braking to act on molten steel disposed in the mold, when the molten steel is supplied at 5 ton/min or more.

ADVANTAGEOUS EFFECTS OF THE INVENTION

[0013] According to the method of continuous casting of steel according to an embodiment of the present invention, it is possible to stably produce cast slabs with good surface quality, even with varying types of steel and casting conditions. Further, in the embodiment of the present invention, the occurrence of break-out can be controlled and a stable casting operation can be achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014]

FIG. 1 illustrates the configuration of the dual-purpose coil used in the method of the present invention. FIG. 1 (a) is a horizontal sectional view. FIG. 1 (b) is a vertical sectional view.

FIG. 2 is a vertical sectional view schematically showing the flow state of in-mold molten steel in a conventional continuous casting method.

BRIEF DESCRIPTION OF THE REFERENCE NUMERALS

[0015]

1	Immersion nozzle
2	Molten steel
3	Mold
3a	Narrow side
3b	Wide side
5	Dual-purpose coil
5 a	Teeth
5b	Inner winding
5c	Outer winding
5d	Core

PREFERRED EMBODIMENTS

[0016] The present invention specifies a mode for applying a current to a dual-purpose coil according to the composition of the molten steel and the amount of molten steel supplied when performing continuous casting of steel using a dual-purpose coil that is capable of serving both functions of electromagnetic braking and electromagnetic stirring.

EMBODIMENTS

[0017] FIG. 1 illustrates the preferred embodiments of the present invention and a process from its initial conception of the present invention to its solution of the problems of the prior art.
[0018] The inventors have studied how to selectively apply electromagnetic braking or electromagnetic stirring to casting conditions when performing continuous casting of steel using a dual-purpose coil as described in Patent Reference 2.
[0019] Electromagnetic braking may have the effect of reducing longitudinal cracks caused by uneven solidifying of molten steel, and inhibiting re-melting of the solidifying shell to thereby control the occurrence of break-out. The reason for this is that electromagnetic braking reduces the flow velocity of the molten steel that is discharged from the immersion nozzle, so that the flow velocity of the molten steel is lower when it collides against the solidifying shell.
[0020] On the other hand, electromagnetic stirring has the effect of preventing surface defects in cast slabs by increasing the flow velocity of the molten steel below the meniscus by adding a flow of molten steel that is parallel to the solidifying shell, thereby preventing air bubbles and inclusions from being trapped in the solidifying shell.
[0021] The present inventors conducted investigations in which when selectively applying electromagnetic braking or electromagnetic stirring according to the casting conditions, they varied the concentration of carbon, a basic component of steel, and the amount of molten steel supplied to the mold which is determined by the casting speed and the sectional area of the mold.
The reason that the amount of molten steel supplied is specified, instead of setting the casting speed as a parameter, is that the amount of molten steel discharged from the immersion nozzle is a primary parameter of molten steel flow in the mold, and thus, the amount of molten steel supplied is a more appropriate parameter than the casting speed for determining the method of controlling the flow of molten steel.
[0022] The following is an explanation of the results of the investigations conducted by the inventors. Molten steel was cast having the compositions given in Table 1 below using a vertical-curved mold continuous caster capable of producing slabs having a width of 1500 mm and a thickness of 270 mm.
[0023]

TABLE 1

Type of Steel	C	Mn	Si	P	S	Al	Ti	Nb
A1 (low carbon steel)	0.0051	0.24	0.01	0.07	0.006	0.02	0.06	0.014
A2 (low carbon steel)	0.05	0.03	0.01	0.01	0.008	0.03	Tr	Tr
A3 (low carbon steel)	0.06	0.14	Tr	0.01	0.002	0.03	Tr	Tr

(continued)

Type of Steel	C	Mn	Si	P	S	Al	Ti	Nb
B1 (ultra low carbon steel)	0.0050	0.05	0.03	0.01	0.003	0.02	Tr	Tr
B2 (ultra low carbon steel)	0.0025	0.35	0.01	0.04	0.004	0.04	0.01	0.005
C1 (Hypoperitectic steel)	0.07	0.52	0.09	0.01	0.004	0.01	Tr	Tr
C2 (hypoperitectic steel)	0.1	1.1	0.05	0.02	0.004	0.01	Tr	Tr
C3 (hypoperitectic steel)	0.16	0.45	0.2	0.02	0.012	0.05	0.01	0.017
(Unit: mass %) Note: Low carbon steel, ultra low carbon steel, and hypoperitectic steel all have residual iron and unavoidable impurities.								

[0024] FIG. 1 shows a dual-purpose coil used in casting, and its typical dimensions. In FIG. 1, Reference Numeral 5 represents two dual-purpose coils arranged continuously on respective wide sides 3b of a mold 3. As illustrated in FIG. 1, two teeth 5a are provided with inner windings 5b, and these two teeth are further united by outer windings 5c. It should be noted that Reference Numeral 5d is a core, the upper end of which is at the same height as the meniscus, and Reference Numeral 6 is a back-up plate installed on the outer side of the mold 3.

[0025] Specifications for the dual-purpose coil, which functions both as an electromagnetic brake and as an electromagnetic stirrer, are given below. Casting conditions are given in Table 2, and casting results are given in Table 3.

(Dual-Purpose Coil Specifications)

[0026] Electromagnetic force at the center of the mold in the direction of thickness: 3000 Gauss Frequency: 4.0 Hz
Current applied to each excitation coil: 45,000 ampere turns
Alternating current phase: 120°, 3-phase alternating current

[0027]

TABLE2

	No.	Type of Steel	Casting Speed (m/min)	Electromagnetic Stirring	Electromagnetic Braking	Amount of Molten Steel Supplied (t/min)
Working Examples	1	A2	1.3	On		3.7
	2	A2	1.5		On	4.3
	3	A2	1.7		On	4.8
	4	A2	2.0		On	5.7
	5	B2	1.3	On		3.7
	6	B2	1.5	On		4.3
	7	B2	1.7	On		4.8
	8	B2	2.0		On	5.7
	9	C2	1.3		On	3.7
	10	C2	1.5		On	4.3
	11	C2	1.7		On	4.8
	12	C2	2.0		On	5.7
	13	A1	1.38	On		3.9
	14	A3	1.41		On	4.0
	15	B1	1.73	On		4.9
	16	B3	1.76		On	5.0
	17	C1	1.02	On		2.9
	18	C3	1.06		On	3.0
Comparative Examples	21	A2	1.3			3.7
	22	A2	1.5			4.3
	23	A2	2.0			5.7
	24	B2	1.3			3.7
	25	B2	1.8			5.3
	26	C2	1.02			2.9
	27	C2	1.5			4.3
	28	C2	1.7			4.8

[0028]

TABLE 3

	No.	Break-out Rate	Surface Defect Rate (%)
Working Examples	1	0.1 time/year	0.2
	2	0.1 time/year	0.2
	3	0.1 time/year	0.2
	4	0.1 time/year	0.2
	5	0.1 time/year	1.0
	6	0.1 time/year	1.0
	7	0.1 time/year	1.0
	8	0.1 time/year	1.5
	9	0.2 time/year	0.3
	10	0.2 time/year	0.3
	11	0.2 time/year	0.3
	12	0.3 time/year	0.3
	13	0.2 time/year	0.3
	14	0.1 time/year	0.3
	15	0.2 time/year	1.0
	16	0.1 time/year	1.2
	17	0.1 time/year	0.5
	18	0.1 time/year	0.5
Comparative Examples	21	0.2 time/year	3.0
	22	0.8 time/year	0.2
	23	0.8 time/year	0.2
	24	0.2 time/year	8.0
	25	0.2 time/year	8.5
	26	0.2 time/year	1.3
	27	5 times/year	1.0
	28	5.5 times/year	1.0

[0029] Turning to Table 2, steel in the type A group was a low-carbon aluminum-killed steel having a carbon concentration greater than 0.0050% and less than 0.07% in terms of mass percentage. In type A steel, uneven solidifying did not readily occur, and when the slabs were checked for surface defects, the rate of occurrence was not high. Therefore, even at a high molten steel supply rate of 5.7 ton/min, casting could be carried out, even without activating conventional electromagnetic braking or electromagnetic stirring (Comparative Example 23).

[0030] However, if electromagnetic braking was not activated, when the amount of molten steel supplied was 4 ton/min or greater, the break-out rate increased (See Comparative Examples 22 and 23). On the other hand, if the amount of molten steel supplied was less than 4 ton/min, surface defects frequently occurred in the slabs when electromagnetic stirring was not activated (See Comparative Example 21).

[0031] By contrast, if the amount of molten steel supplied was 4 ton/min or higher, stable casting could be achieved by activating electromagnetic braking (See Working Examples 2-4 and 14). Furthermore, if the amount of molten steel supplied was less than 4 ton/min, the occurrence of surface defects in slabs could be reduced by activating electromagnetic stirring (See Working Examples 1 and 13).

[0032] Steel in the type B group was a ultra low carbon steel having a carbon concentration of 0.0050% or less in terms of mass percentage. Although, generally speaking, in type B steel uneven solidifying did not readily occur, the rate of occurrence of surface defects in the slabs was extremely high. When electromagnetic stirring or electromagnetic braking was not activated, surface defects occurred in the slabs even if the amount of molten steel supplied was less than 5 ton/min (See Comparative Example 24), and if the amount of molten steel supplied was 5 ton/min or greater, surface defects frequently occurred in the slabs (See Comparative Example 25).

[0033] Using steel in the type B group, if the amount of molten steel supplied was less than 5 ton/min, it was effective to activate electromagnetic stirring, and indeed the effect was particularly significant (See Working Examples 5-7 and 15). Furthermore, if the amount of molten steel supplied was 5 ton/min or greater, it was also effective to activate electromagnetic braking (See Working Examples 8 and 16).

[0034] Steel in the type C group was a hypoperitectic steel having a carbon concentration of 0.07% or higher and 0.16% or less in terms of mass percentage. In type C steel, uneven solidifying readily occurs, and the occurrence of surface defects was low. Using steel in the type C group, when electromagnetic braking or electromagnetic stirring was not activated, if the amount of molten steel supplied was 4 ton/min or greater, longitudinal cracks and re-melting occurred, and the rate of occurrence of break-out was extremely high (See Comparative Examples 27 and 28).

[0035] Using steel in the type C group, the rate of occurrence of break-out could be reduced by activating electromagnetic stirring when the amount of molten steel supplied was less than 3 ton/min (See Working Example 17), and by activating electromagnetic braking when the amount of molten steel supplied was 3 ton/min or greater (See Working Examples 9-12 and 18).

[0036] These results show that electromagnetic braking was very effective in the following cases: where the molten low carbon steel was supplied at 4 ton/min or greater; where ultra low carbon molten steel was supplied at 5 ton/min or greater; and where hypoperitectic molten steel was supplied at 3 ton/min or greater. In particular, electromagnetic braking was extremely effective in the case of hypoperitectic steel, in which uneven solidifying and re-melting of the solidifying shell readily occurred.

[0037] On the other hand, if the amount of the molten steel of the above types that was supplied was less than the amounts given above, then electromagnetic stirring was very effective. In the case of ultra low carbon steel in particular, there were instances in which the surface defect rate could be high, but the activation of electromagnetic stirring was found to be very effective in eliminating such defects.

[0038] The present invention is of course not limited to the foregoing examples, and the embodiments can of course be suitably modified, as long as they are within the scope of the technical ideas recited in the claims.

[0039] For example, the alternating current does not have to be 3-phase, but it can have a higher number of phases, as long as the current phase difference is from between about 90° to about 120°.

INDUSTRIAL APPLICABILITY

[0040] The present invention described above can be applied to continuous casting using a curved mold, a vertical mold, or any mold shape, as long as it involves continuous casting. Moreover, the present invention can be applied not only to continuous casting of slabs, but also to continuous casting of blooms.

Claims

1. A method of continuous casting of a steel that specifies a mode for applying current to a dual-purpose coil, the method comprising:

   arranging at least two polar iron cores in the same number on the outer periphery of a wide side of a mold, for a total of (2n + 2) on the outer periphery of the wide side of the mold, wherein n is a natural number, wherein each of the polar iron cores comprises a first excitation coil wound around outer periphery of the magnetic polar iron core, and wherein a second excitation coil is wound around the outer periphery of two of the at least two magnetic polar iron cores, such that the two magnetic polar iron cores are wound together;
   applying, in the case of electromagnetic stirring, a multi-phase alternating current to the excitation coils of all of the electromagnetic coils, wherein the multi-phase alternating current has at least 3 phases, each phase having a phase difference from between about 90° to about 120°;
   applying, in the case of electromagnetic braking, a direct current to the second excitation coil or to the first excitation coils wound around the two magnetic polar iron cores and the second excitation coil, and
   selectively activating the electromagnetic braking or the electromagnetic stirring according to the composition of the molten steel and the amount of molten steel supplied.

2. A method of continuous casting of a steel according to claim 1, wherein, when the constituent carbon concentration of the molten steel supplied to the mold is at least 0.07% and 0.16% or less in terms of mass percentage:

1) a multi-phase alternating current of 3 phases or more is applied to the first and second electromagnetic coils, thereby causing electromagnetic stirring to act on molten steel disposed in the mold, when the molten steel is supplied at less than 3 ton/min, and
2) a direct current is applied to the first and second electromagnetic coils in order to cause electromagnetic braking to act on molten steel disposed in the mold, when the molten steel is supplied at 3 ton/min or more.

3. A method of continuous casting of a steel according to claim 1, wherein, when the constituent carbon concentration of the molten steel supplied to the mold is greater than 0.0050% and less than 0.07% in terms of mass percentage:

1)a multi-phase alternating current of 3 phases or more is applied to the first and second electromagnetic coils in order to cause electromagnetic stirring to act on molten steel disposed in the mold, when the molten steel is supplied at less than 4 ton/min, and
2) a direct current is applied to the first and second electromagnetic coils in order to cause electromagnetic braking to act on molten steel disposed in the mold, when the molten steel is supplied at 4 ton/min or more.

4. A method of continuous casting of a steel according to claim 1, wherein, when the constituent carbon concentration of the molten steel supplied to the mold is 0.0050% or less in terms of mass percentage:

1) a multi-phase alternating current of 3 phases or more is applied to the first and second electromagnetic coils in order to cause electromagnetic stirring to act on molten steel disposed in the mold, when the molten steel is supplied at less than 5 ton/min, and
2) a direct current is applied to the first and second electromagnetic coils in order to cause electromagnetic braking to act on molten steel disposed in the mold, when the molten steel is supplied at 5 ton/min or more.

Figure 1

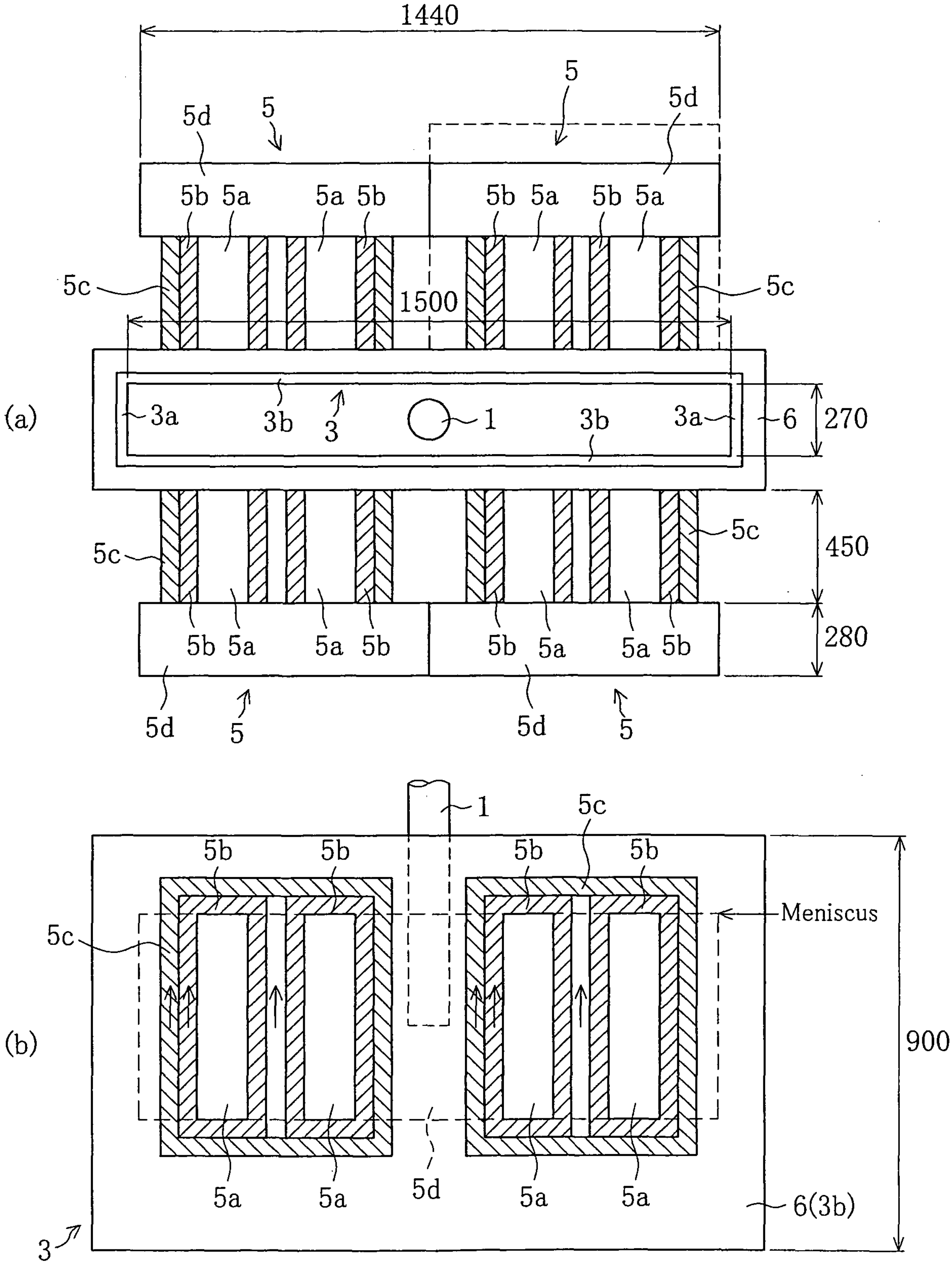

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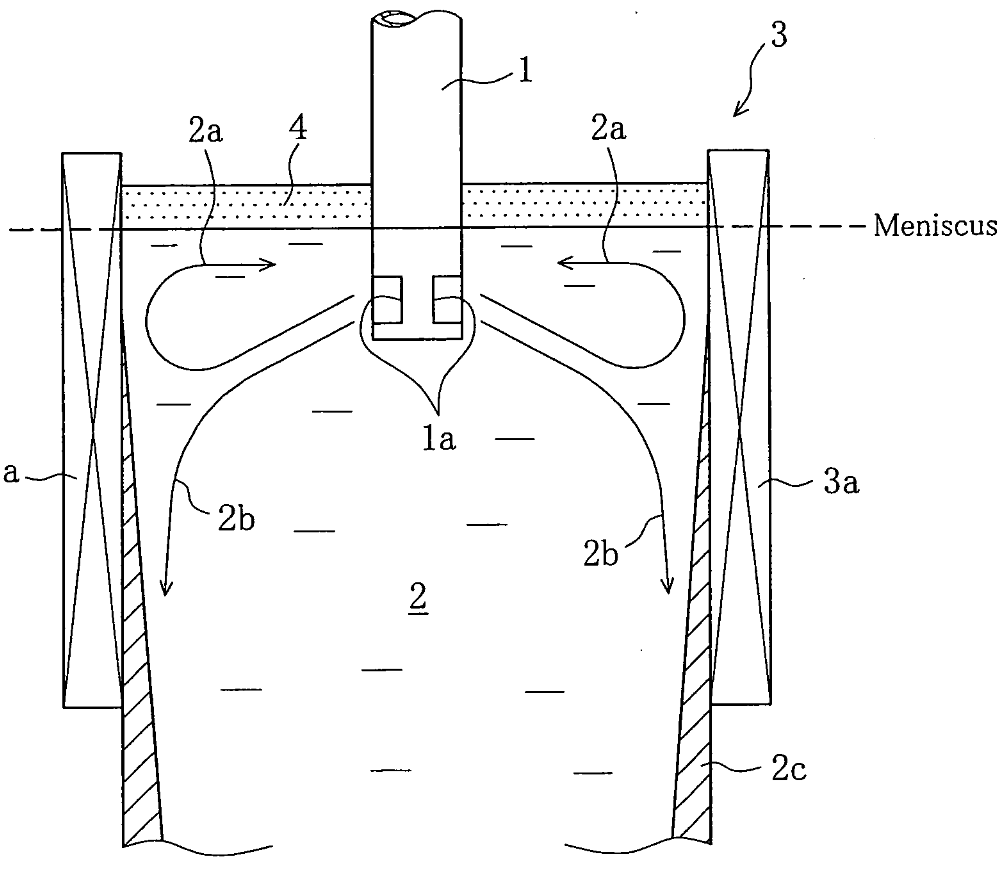
Figure 2



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2008/057511

A. CLASSIFICATION OF SUBJECT MATTER
B22D11/115(2006.01)i, *B22D11/04*(2006.01)i, *B22D11/11*(2006.01)i, *B22D11/18*(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)
B22D11/115, B22D11/04, B22D11/11, B22D11/18

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

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2007-7719 A (Sumitomo Metal Industries, Ltd.), 18 January, 2007 (18.01.07), Claim 1; Fig. 1 (Family: none)	1-4
A	JP 2005-349454 A (Sumitomo Metal Industries, Ltd.), 22 December, 2005 (22.12.05), Claims 1, 2 (Family: none)	1-4
A	JP 2004-322179 A (Sumitomo Metal Industries, Ltd.), 18 November, 2004 (18.11.04), (Family: none)	1-4

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

* Special categories of cited documents:
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Date of the actual completion of the international search	Date of mailing of the international search report
19 May, 2008 (19.05.08)	27 May, 2008 (27.05.08)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

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

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2008/057511

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2001-9559 A (Kawasaki Steel Corp.), 16 January, 2001 (16.01.01), (Family: none)	1-4

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REFERENCES CITED IN THE DESCRIPTION

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- JP 2007007719 A **[0005]**