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(54) Title: A CASTING MOLD AND A METHOD FOR MEASURING TEMPERATURE OF A CASTING MOLD

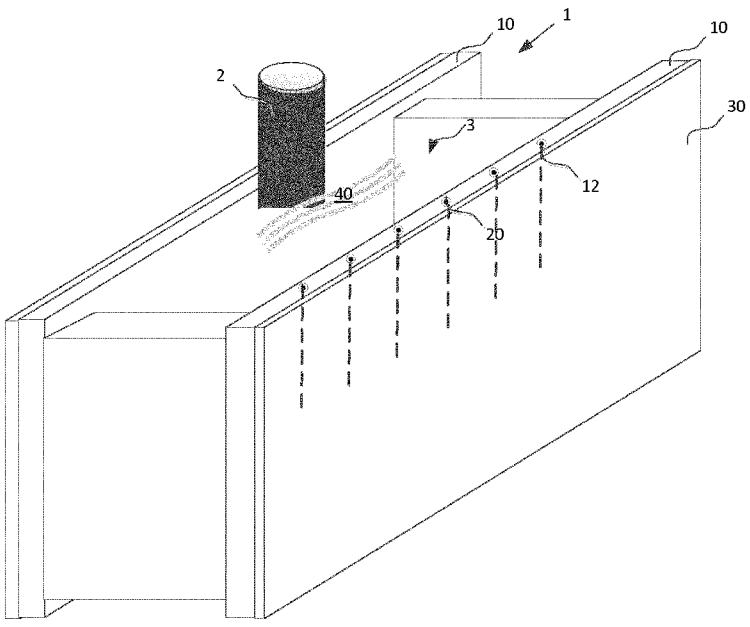


Fig. 1

(57) Abstract: The present invention relates to a casting mold (1) comprising a copper plate (10) and a plurality of optical fibers (20), each (20) of the optical fibers having a plurality of temperature measuring points (22) arranged for measuring temperature of the copper plate (10) while casting, wherein a molten metal (40) is cast into the casting mold (1) along an axis (Y), wherein the optical fibers (20) are built-in the copper plate (10) and are arranged at least upper part of the copper plate. The present invention further relates a method measuring temperature of at least one copper plate of a casting mold, wherein a molten metal is cast into the casting mold along an axis, the method comprising determining by calculation or measurement an actual molten flow of the molten metal in the mold (S1 0), building-in a plurality of optical fibers into the copper plate based on the calculated/measured actual molten flow (S20), and arranging the optical fibers inside of the copper plate at least upper part of the copper plate (S30).

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A CASTING MOLD AND A METHOD FOR MEASURING TEMPERATURE OF A CASTING MOLD

FIELD OF THE INVENTION

The present invention relates to a casting mold comprising a copper plate and a plurality of optical fibers arranged for measuring temperature of the copper plate, each of the optical fibers having a plurality of temperature measuring points arranged for measuring temperature of the copper plate while casting. The invention also relates a method for measuring temperature of a casting mold plate.

BACKGROUND

It is well-known in the art that it is important to monitor temperature of a casting mold that is operating at a high speed.

During the casting process, a typical period of temperature variation is less than ten seconds. This is because that the temperature depends on a heat flux of molten steel. The heat flux may vary depending on a melt temperature, a mold powder and the molten steel speed of the movement. Typically the molten steel flow will change during a casting process, which results in a temperature profile of the mold with a dimension-scale less than 100 mm in wide side of the mold and 10 mm in the height of the mold. If the temperature is uniform in the molten metal surface layer the solidification is uniform over the whole strand width. If, on the other hand, the temperature is not uniform in the molten metal surface layer the cast surface will solidify non-uniformly and the risk for surface cracks, inclusion entrapment and uneven solid shell will increase. Also if the solid shell is uneven there is a risk both for lower structural strength and re-melting of the solid shell that can result in a so called break-out below the mold where the shell is broken and the steel flows out causing major damage to the surrounding equipment.

The temperature determination may be made by measuring the temperature of a copper plate of the casting mold. For measuring, determining and monitoring the temperature of the copper plate, thermocouples are mounted in holes in the copper plate. The number of the thermocouples is limited, for example up to 20 pieces due to the geometry constraints of the copper plate. Thus, the resolution of measured temperatures is low.

In a recent development, optical fibers are used for measuring temperatures of a copper plate to achieve a higher resolutions of measured temperature.

US 2011/0167905 A1 describes a method comprising detecting the temperature distribution in the area of a casting level over the height of a mold by using a measuring thread and/or a measuring probe to determine the height of the casting level, where the measuring thread and/or measuring probe is detachably mounted on a copper plate of the mold and comprises fiber-optic sensors. The height of the casting level is determined from the detected temperature distribution by using an evaluation device. A further measuring probe for temperature detection may be detachably arranged in the area of the lower end of the mold.

PCT/EP2009/004901 describes another method, wherein laser light is passed through optical fibers used as sensors. Grooves are arranged made on the outer sides of copper plates of a mold. The optical fibers are located in these grooves. The fibers have a meandering arrangement in the grooves. At least two fibers are arranged in each groove. The grooves are located between cooling channels on the outside of the plates. The fibers are arranged in the fixed side, the detachable side and preferably in both narrow sides of the mold.

OBJECTS AND SUMMARY OF THE INVENTION

It is an object of the present invention to achieve more accurate tem-

perature measurement in the mold of a continuous caster and consequently to enable a better control of a casting process and thereby achieving higher cast steel quality and higher process safety.

In a first aspect, there is a casting mold comprising a copper plate and a plurality of optical fibers, each of the optical fibers having a plurality of temperature measuring points arranged for measuring temperature of the copper plate while casting, wherein a molten metal is cast into the casting mold along an axis, wherein the optical fibers are built-in the copper plate and are arranged at least in the upper part of the copper plate so that the temperatures of at least upper part of the copper plate are measured.

The copper plate is located adjacent to the solidifying shell and its temperature reflects the molten metal temperature and by measuring the temperature of full length on at least upper part of the copper plate important information on the casting process is thus obtained.

During a casting process, temperature in the copper plate is varying over time and position. A temperature sensing must be able to monitor these variations in order to monitor temperature distributions of the copper plate.

It is particularly of importance to monitor an upper part of the copper plate to be able at an early stage to extract information of break-out tendencies and alternations in flow pattern also to learn about best casting practice in relation thermal information.

By non-detachably building/embedding the optical fibers into the copper plate, a highly robust and reliable measuring system is achieved.

In one embodiment of the invention, the optical fibers are arranged into at least upper 300 mm of the copper plate.

In another embodiment of the invention, the optical fibers are arranged into the entire wide side and at least upper 400 mm of the copper plate.

In a further embodiment of the invention, the optical fibers are arranged into the entire area of the copper plate, which make it possible to collect complete information regarding the thermal changes in the solidification shell during casting and to learn about best casting practice in relation to thermal information.

In order to build-in the optical fibers into the copper plate, a plurality of holes are arranged in parallel and/or perpendicular with the axis of casting direction for accommodating the optical fibers. Each of the holes has a diameter of 0.3-1.2 mm. The holes may be further grouped and a distance between two groups is in a range of 100-400 mm. A distance between two holes in the same group is in a range 10-50 mm.

By grouping the optical fibers into groups and arranging the groups with distances, a total amount of the temperature measuring points may reach at least 500 or alternatively 1500 thus to achieve a high resolution. For achieving even higher temperature and position measuring resolution, a total amount of the temperature measuring points of at least 3000 may be arranged.

In a second aspect of the invention, there is a method provided for measuring temperature of at least one copper plate of a casting mold, wherein a molten metal is cast into the casting mold along an axis, the method comprising determining by calculating or measuring an ideal molten flow of the molten metal in the mold, building-in a plurality of optical fibers into the copper plate based on the calculated/measured actual molten flow and arranging the optical fibers inside of the copper plate at least upper part of the copper plate.

In one embodiment of the invention, the method further comprising arranging a plurality of holes in parallel and/or perpendicular with the axis of the casting direction for accommodating the optical fibers.

In yet another embodiment of the invention, after receiving the meas-

urements of temperatures and the method comprises step of determining temperature distribution of the copper plate by comparing the measured result with the ideal molten flow.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be explained more closely by the description of different embodiments of the invention and with reference to the appended figures.

Fig.1 illustrates a side perspective schematic view of a casting mold according to a first embodiment of the invention, wherein multiple optical fibers are built-in the upper region of a copper plate of the casting mold.

Fig.1a shows a cross-section of a casting mold of the embodiment of Fig.1a.

Fig.1b illustrates a cross-section of a casting mold according to a second embodiment of the invention, wherein multiple optical fibers are vertically built-in at least 300mm from the upper edge of the copper plate.

Fig.1c illustrates a cross-section of a casting mold according to a third embodiment of the invention, wherein multiple optical fibers are horizontally built-in at least 400mm from the upper edge of the copper plate.

Fig.1d illustrates a cross-section of a casting mold according to a fourth embodiment of the invention, wherein multiple optical fibers are built-in entire region of the wide side of a copper plate in a meshed manner.

Fig.2 illustrates a side perspective schematic view of a casting mold, according to a fifth example of the invention, wherein optical fibered are grouped together.

Fig.3 illustrates an optical fiber built into a copper plate of the casting mold according to Figure 1.

Fig.4 shows a flow chat of monitoring temperature of a casting mold, according to a further embodiment of the invention.

Fig.5 shows a diagram of measured temperatures of a mold copper plate.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

It should be understood that the scope of the invention must not be limited the presented embodiments, it shall cover other embodiments that are obvious to a person skilled in the art.

Figure 1 is a side perspective view of a casting mold 1 for casting molten metal 40 such as steel, copper or aluminum. The casting mold 1 comprise a nozzle or a pouring spout 2 and a hollow cavity 3 of the desired shape. In this example, a rectangle cavity ~~vessel~~ is illustrated. The cavity 3 is typically constructed in a rectangle shape with a wide side and a narrow side and further includes an external structure 30 and an interior copper plate 10. The molten metal 40 is typically in contact with the interior copper plate 10.

During a casting process, the molten metal 40 is poured through the nozzle or the pouring spout 2 into the cavity 3 and solidified. The solidified part is also known as a cast strand, which is ejected or broken out of the mold as slabs or billets. It is known that the solidification of the surface of a cast strand is determined by the temperature distribution of the molten metal in the mold.

In order to monitor the temperature distribution of the molten metal, a plurality of optical fibers 20 are fixedly built inside of the interior cop-

per plate. Each of the optical fibers 20 having a plurality of temperature measuring/sensing points 22 arranged for measuring temperature of the copper plate. A total number of temperature measuring/sensing points 22 on each of the optical fibers 20 may be in a range of 50-100 for example. Figure 3 illustrates an optical fiber 20 with a plurality of measuring points 22. The temperatures are measured and collected and analyzed while casting a molten metal into the casting mold along an axis Y, wherein the casting direction is denoted by arrow A. The installation of the optical fibers enables extraction of information about break-out tendencies and alternations in flow pattern, and therefore provides a better control of the casting process in relation thermal information. Furthermore, the fixedly built-in optical fibers 20 provides a robust and easy installation.

In Figure 1, the optical fibers 20 are arranged in the upper part of the copper plate so that the temperatures of at least upper part of the copper plate are sensed and measured. To facilitate the built-in construction, a plurality of holes 12 are arranged into the copper plate 10, each of the holes 12 is configured to accommodate an optical fiber 20.

Figure 1a shows a cross-section view of a casting mold according to one example of the invention, which shows that the holes 12 are arranged from the upper edge of the copper plate into the copper plate in parallel with the axis Y, i.e. along with a direction of the casting and the optical fibers are fixedly built into the copper plate.

Figure 1b shows a cross-section view of another example of the invention, wherein the holes 12 are arranged in parallel with the axis Y into the copper plate at least 300 mm from the upper edge of the wide side of the copper plate for accommodating the optical fibers 20. In this example, the arrangement is applied to a copper plate that has height 900 mm, width 1850 mm and thickness 30-50 mm. However, it can be applied for other dimensions as well with proper adjustments.

Furthermore, holes 20 may be also arranged in perpendicular with the axis Y as illustrated in Figure 1c. In this example, the holes 12 are

arranged such that the optical fibers may measure a region with a dimension of at a distance 400mm from the upper edge and the wide side of the copper plate.

A further alternative embodiment as shown in Figure 1d is that holes 12 are arranged in a mesh manner into entire area of the copper plate for housing the optical fibers 20 such that the optical fibers may measure entire region of the copper plate.

In any of the above cases shown in Figures 1, 1a-1d, the holes 20 are arranged 5-20 mm in the copper plate from the side facing the molten metal.

With reference to Figure 2, each of the holes 12 has a diameter d1 of 0.3-1.2 mm. It is advantageous that a hole is constructed within this range since a relative small hole has a relative small impact on the strength of the mold copper plate on one hand. On the other hand, a time constant for temperature variation depends on sizes of optical fibers and holes. The small diameter of a hole provides a short time constant and a faster reaction time to the measured temperature of the copper plate. The holes 20 may be further grouped and a distance d2 between two groups is in a range of 100-400 depending the dimension of the mold. Figure 5 shows a diagram of measured temperatures in a copper plate for a mold having a wide side of 1600mm, wherein temperatures typically vary at a point of the narrow side, the middle/center of the mold where the nozzle is placed and two points in between. The X-axis of the diagram is a distance from middle/center of the mold and Y-axis is distance from top of the mold. The temperature variations occur particularly at upper part at a location 100mm from the top of the mold and at a lower part at a location 350mm from the top of the mold; and within this region, the closer it is to the top, the higher a temperature is. Thus, by grouping the optical fibers with this range, the temperature variations will thus be captured. A distance d3 between two holes in the same group is in a range 10-50 mm in order to capture time variation of the molten metal. The arrangement of the optical fibers in groups provides better local resolutions and

densities in some particular regions of the copper plate to achieve different requirements of casting.

By grouping the optical fibers into groups and arranging the groups with distances, a total amount of the temperature measuring points may reach at least 500 or alternatively 1500 thus to achieve a high resolution. For achieving even higher temperature and position measuring resolution, a total amount of the temperature measuring points of at least 3000 may be arranged so that even high time and position accuracy can be achieved.

The optical fibers 20 shown in Figures 1, 1a-1c and 2 may be further connected to a temperature analysis unit, from which a laser light is guided into the optical fibers 20. The temperatures of the measuring/sensing points along each optical fiber may be determined by some of well-known analysis methods, for example, the Fiber Bragg Grating method or FBG method in short). The principal of the method may be found in US 2011/0167905 A1. As it described, the detailed design of Fiber Bragg Gratings analysis method is widely known. The accuracy of the local resolution is a function of the spacing of the impressed measuring/sensing points. A further example of the analysis methods may be OFDR or OTDR By analyzing the measured temperature, the casting process can be better monitored and controlled by a thermal image of interesting meniscus area of the molten metal. Further applications of the measured and analyzed temperatures can be calculation of mechanical stresses and heat flows of the copper plate.

Although Figures 1, 1a-d and 2 illustrate that optical fibers are arranged inside one cooper plate of the mold, it should be understood that it is possible to arrange them into other copper plates of the mold to improve further time and position accuracy.

Figure 4 shows a flow chart of monitoring temperature of a casting mold, according to a further embodiment of the invention, which comprises determining by calculation or measurement an ideal molten flow of the molten metal in the mold (S10), embedding a plurality of optical

fibers into the copper plate based on the calculated/measured actual molten flow (S20), arranging the optical fibers inside of the copper plate at least upper part of the copper plate (S30), wherein a plurality of holes in parallel and/or perpendicular with the axis for accommodating the optical fibers (S40). In this way the temperature pattern of the copper plate, i.e. molten metal is determined based on the measurements of temperatures and can be compared to the ideal flow pattern.

CLAIMS

1. A casting mold (1) comprising a copper plate (10) and a plurality of optical fibers (20), each (20) of the optical fibers having a plurality of temperature measuring points (22) arranged for measuring temperature of the copper plate (10) while casting, wherein a molten metal (40) is cast into the casting mold (1) along an axis (Y), **characterized in** that the optical fibers (20) are built-in the copper plate (10) and are arranged at least upper part of the copper plate.

2. Casting mold of claim 1, wherein the optical fibers are arranged into at least upper 300 mm of the copper plate.

3. Casting mold of claim 1, wherein the optical fibers are arranged into the entire wide side and at least upper 400 mm of the copper plate.

4. Casting mold of claim 1, wherein the optical fibers are arranged into the entire area of the copper plate.

5. Casting mold of any of claims 1-4, wherein a plurality of holes (12) are arranged in parallel and/or perpendicular with the axis (Y) for accommodating the optical fibers.

6. Casting mold of claim 5, wherein each of the holes has a diameter (d1) of 0.3-1.2 mm.

7. Casting mold of claim 5, wherein the holes (12) accommodating the optical fibers (20) are grouped and a distance (d2) between two groups is in a range of 100-400 mm.

8. Casting mold of claim 4, wherein a distance (d3) between two holes in the same group is in a range 10-50 mm.

9. Casting mold of claim 1, wherein a total amount of the temperature measuring points is at least 500.

10. Casting mold of claim 1, wherein a total amount of the temperature measuring points is at least 1500.

11. Casting mold of claim 1, wherein a total amount of the temperature measuring points is at least 3000.

12. A method for measuring temperature of at least one copper plate of a casting mold, wherein a molten metal is cast into the casting mold along an axis, the method comprising

- determining by calculation or measurement an ideal molten flow of the molten metal in the mold (S10),
- building-in a plurality of optical fibers into the copper plate based on the calculated/measured actual molten flow (S20), and
- arranging the optical fibers inside of the copper plate at least upper part of the copper plate (S30).

13. Method of claim 11 comprising arranging a plurality of holes in parallel and/or perpendicular with the axis for accommodating the optical fibers (S25).

14. Method of claim 11 comprising receiving the measurements of temperatures and determining temperature pattern of the copper plate (S40).

15. Method of claim 11 comprising comparing the measured result with the ideal molten flow (S50).

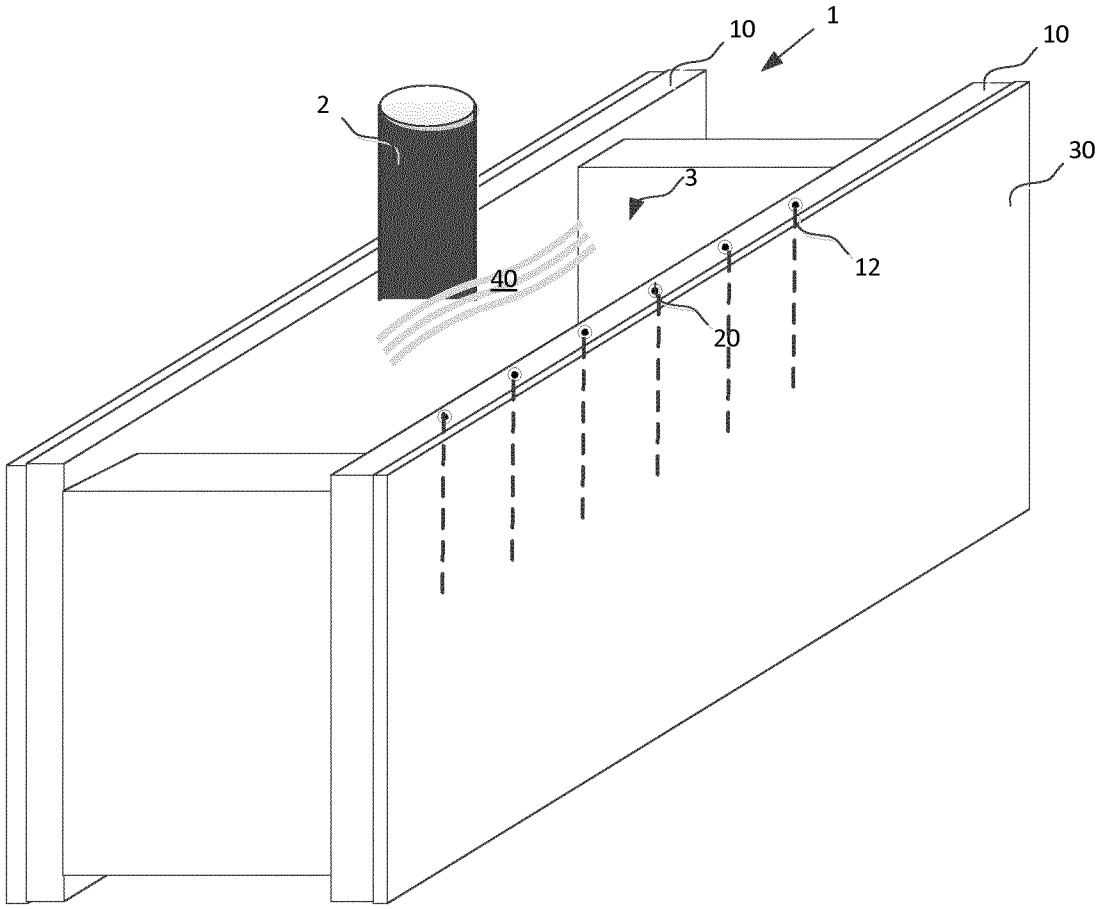


Fig. 1

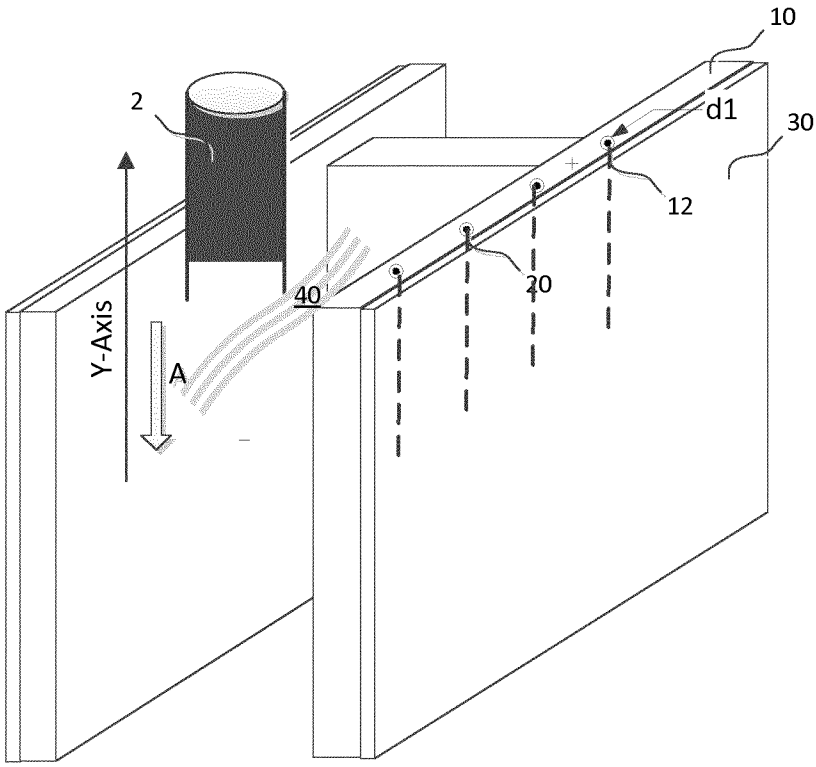


Fig. 1a

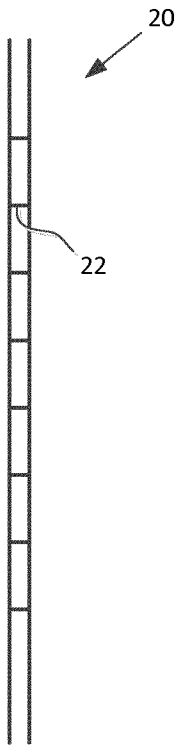


Fig. 3

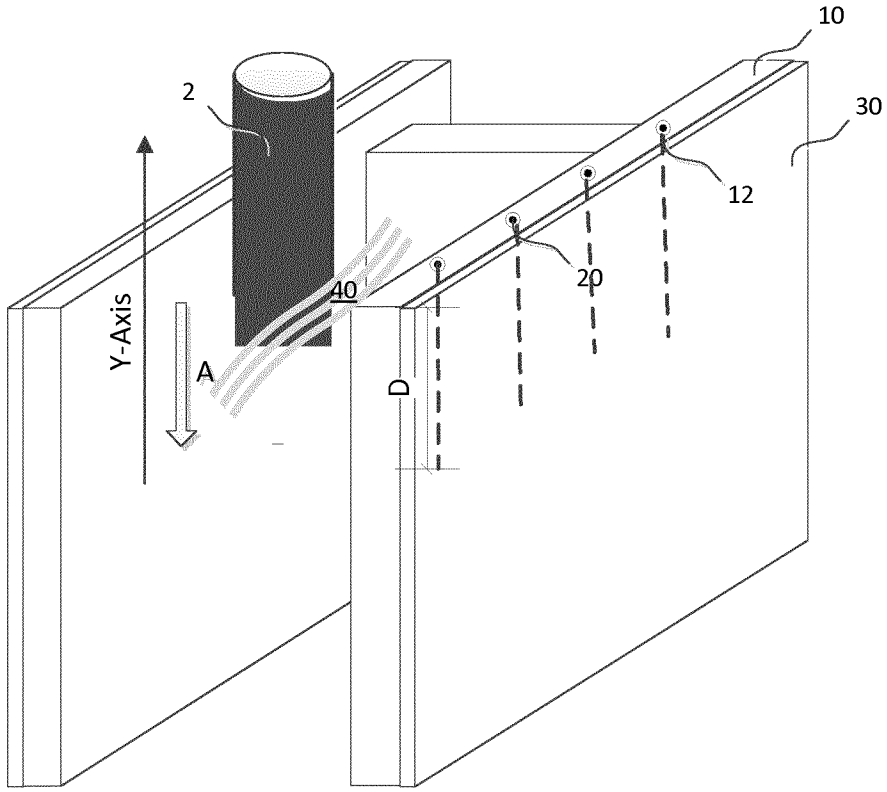


Fig. 1b

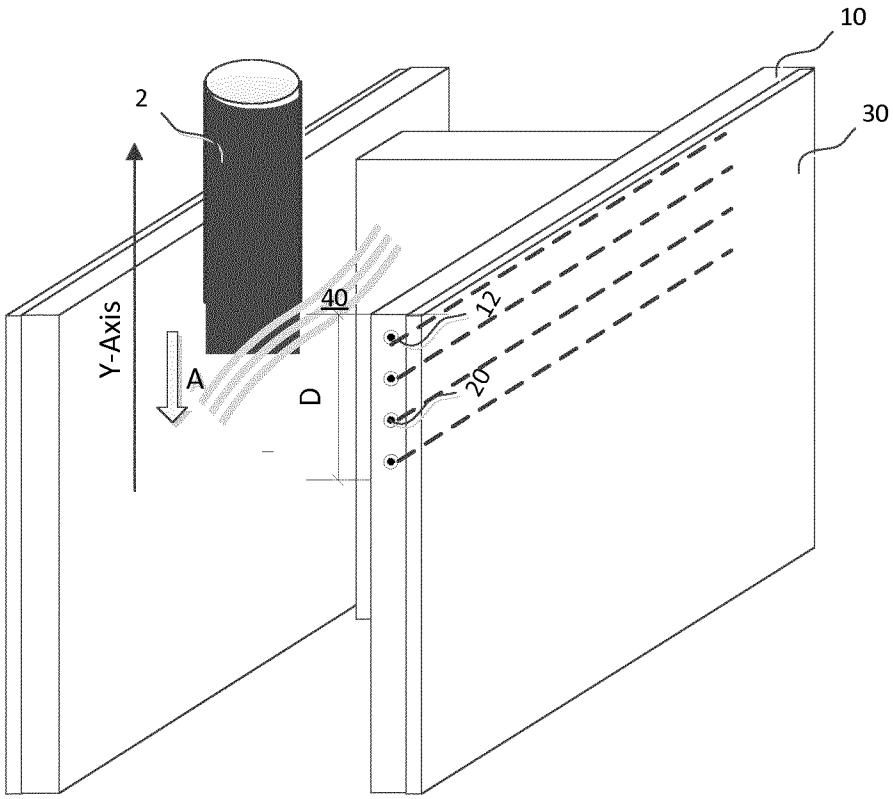


Fig. 1c

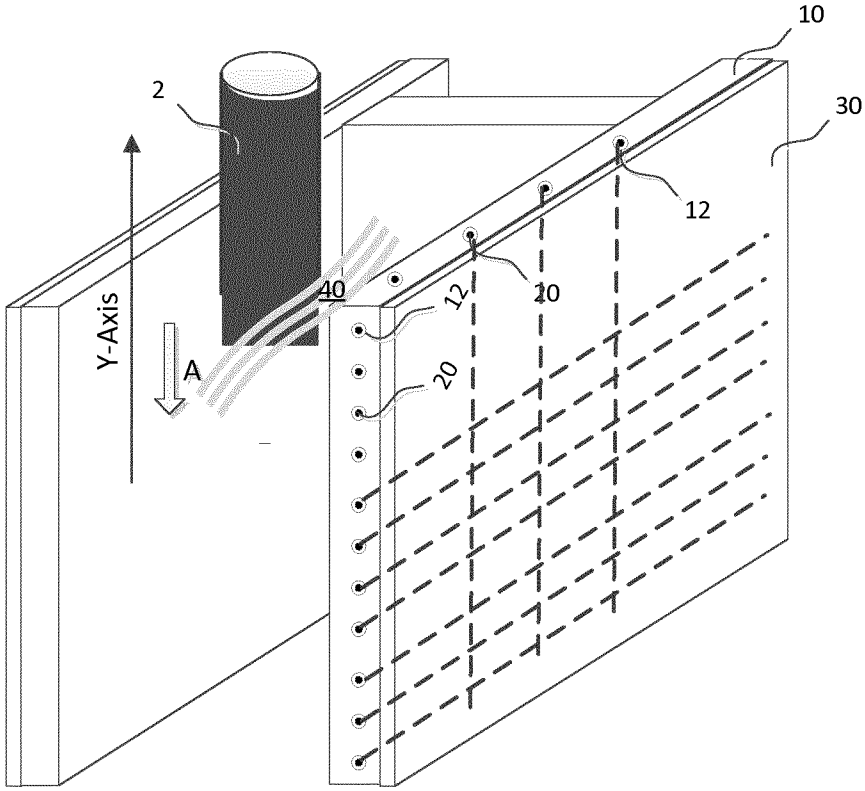


Fig. 1d

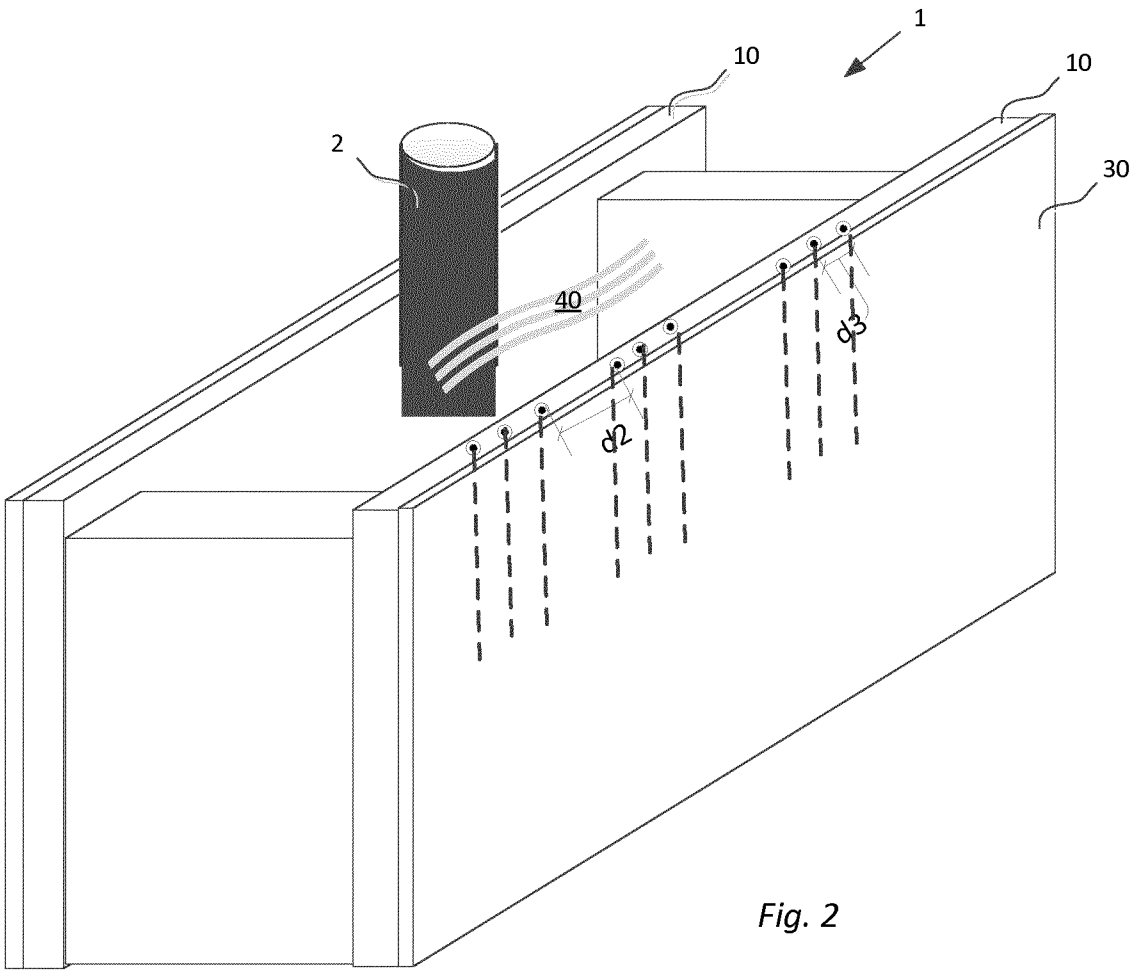


Fig. 2

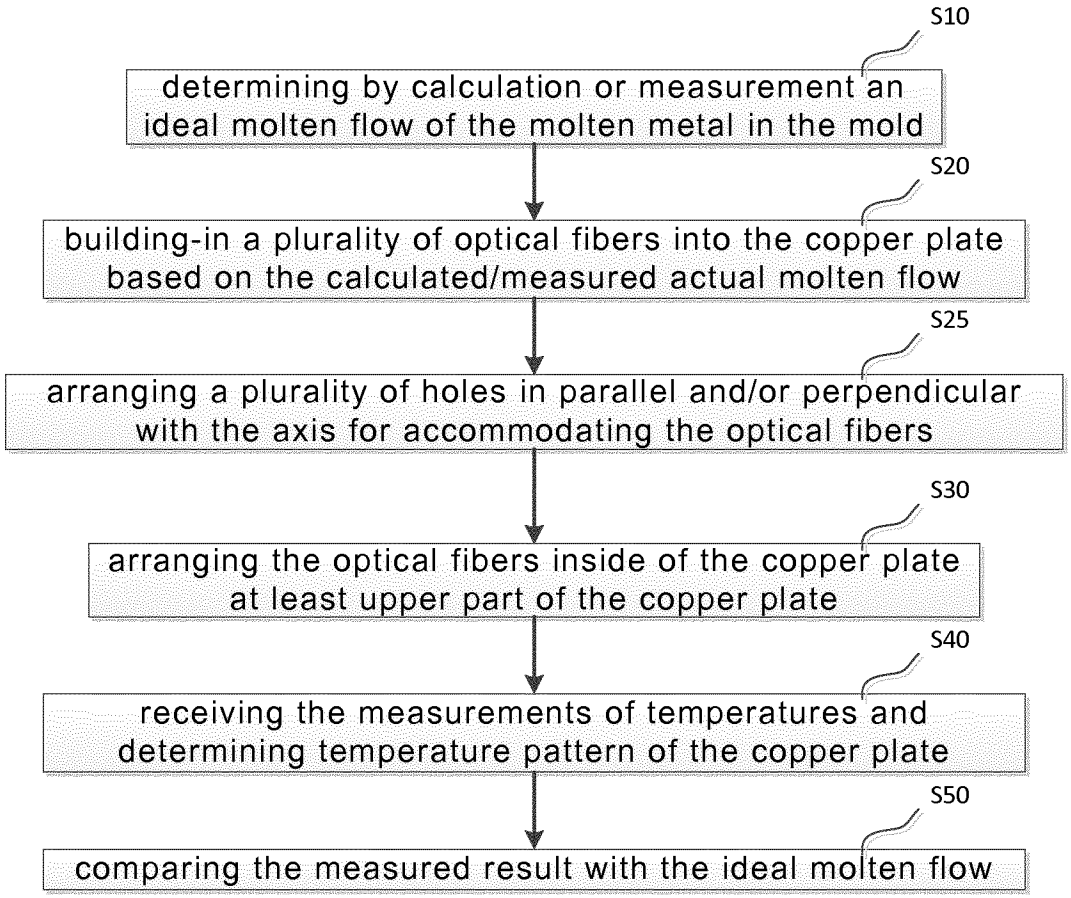

S10
determining by calculation or measurement an ideal molten flow of the molten metal in the mold
S20
building-in a plurality of optical fibers into the copper plate based on the calculated/measured actual molten flow
S25
arranging a plurality of holes in parallel and/or perpendicular with the axis for accommodating the optical fibers
S30
arranging the optical fibers inside of the copper plate at least upper part of the copper plate
S40
receiving the measurements of temperatures and determining temperature pattern of the copper plate
S50
comparing the measured result with the ideal molten flow

Fig. 4

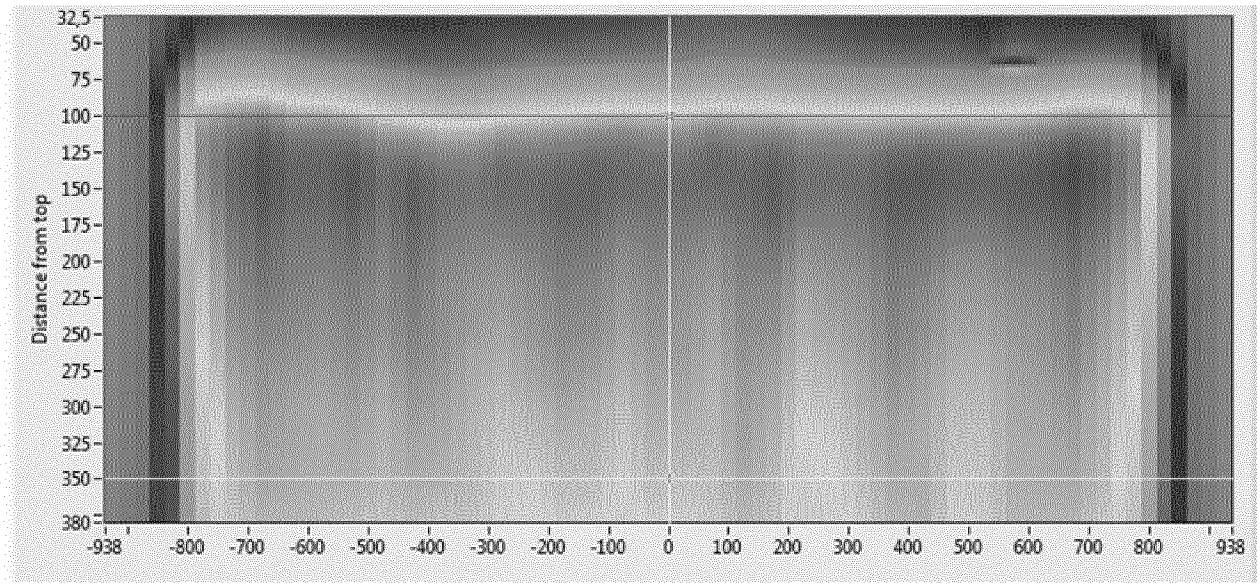

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Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/069244

A. CLASSIFICATION OF SUBJECT MATTER
INV. B22D2/00 B22D11/18 G01K11/32
ADD.

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)
B22D G01K

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

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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X	DE 10 2008 060507 A1 (SMS SIEMAG AG [DE]) 14 January 2010 (2010-01-14) figures 1-3 paragraph [0008] - paragraph [0041]	1-15
X	US 2011/167905 A1 (ARZBERGER MATTHIAS [DE] ET AL) 14 July 2011 (2011-07-14) cited in the application figures 1-7 paragraph [0012] - paragraph [0065]	1-15

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
3 May 2016	17/05/2016

Name and mailing address of the ISA/	Authorized officer
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1

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2015/069244

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