CONTINUOUS ROTARY METHOD OF CASTING METAL UTILIZING A MAGNETIC FIELD

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ABSTRACT
Steel blanks or billets are cast by the continuous rotary casting method by effecting in the molten core of the blank or billet an axial circulation of the liquid metal. This circulation is created by electromagnetic fields induced by inductors which surround the blank or billet. The circulation is downwards near the axis of the blank or billet and upwards along the walls or skin of the blank or billet.

5 Claims, 5 Drawing Figures
CONTINUOUS ROTARY METHOD OF CASTING METAL UTILIZING A MAGNETIC FIELD

This invention relates to an improved method for continuously casting of steel or other metals having similar properties, and relates also to apparatus for carrying out this method and to products obtained by the method.

The invention will be described hereafter with reference to the continuous casting of steel, but it is understood that the invention relates to the continuous casting of metals and alloys having similar properties to steel with particular reference to melting points, which are, for example, between 1,100 and 1,800°C.

The method according to the invention has proved particularly advantageous in the case of high grade steel and special steels, such for example, nickel-chromium or nickel-chromium molybdenum alloys.

It is known that the continuous casting of steel consists of introducing steel in liquid form into an ingot mould cooled, for example, by flowing water, so as to obtain progressive solidification of a bar which is extracted vertically in a downwards direction by means of extraction rollers.

So-called "static continuous" casting methods are known, in which the ingot moulds do not undergo any rotational movement relative to a vertical axis, the products obtained being solely subjected to an axial downwards displacement. This method makes it possible to obtain, under very satisfactory conditions, steel ingots which have a prismatic shape, generally square or rectangular.

The applicants have already conceived a so-called "rotary method" for the continuous casting of steel, in which the ingot mould which ensures the beginning of solidification, the blank being formed and the devices employed for extracting and cutting the formed blank are driven in a continuous rotary movement about a vertical axis, the ingot mould also possibly being capable of being subjected to oscillatory movements of low amplitude about a vertical axis. This method makes it possible to obtain blanks or bars of circular section, the particularly high quality of which makes it possible to obtain, directly by rolling, tubes of high quality steel.

The method which is the object of the present invention is applicable to this latter type of continuous "rotary" casting.

An aspect of the present invention is an improved method for the continuous rotary casting of steel or similar metals, comprising the steps of introducing the liquid metal into an ingot mould, or other mould, rotatable about a vertical axis, effecting vigorous cooling by the downwards extraction of the blank during solidification and by spraying water onto the part of the blank extending below the mould to cool same, and effecting an axial circulation of liquid metal contained inside the blank by the action of electro-magnetic fields induced inside the blank, at least one region of the cooling blank located below the mould.

According to a preferred embodiment of the invention the induced electro-magnetic fields are obtained by groups of inductors provided side-by-side around the solidifying blank, these inductors being supplied with polyphase current so as to create pulsating electro-magnetic fields along the axis of the blank.

It is possible, for example, to create an electro-magnetic field, according to the invention, by means of three inductors supplied with three-phase electric current. When it is desired to create fields over a much greater length of the blank it is possible to use a series of several groups of three inductors supplied with three-phase current.

The electro-magnetic fields used according to the invention are solely intended for ensuring a circulating of liquid metal inside the blank during its solidification, this circulation taking place in the axial direction of the blank, i.e. vertically. This result is obtained by means of the inductors which have been described above due to the fact that these inductors create electro-magnetic fields throughout the section of the blank which is solidifying, these fields nevertheless having a greater value at the periphery of the liquid metal than in its centre.

The result is that in the region subjected to the electro-magnetic fields produced by the inductors, the liquid metal contained in the solidifying blank is displaced in an axial current. This current is directed in a given direction at the centre of the blank, for example, from the bottom to the top, the liquid metal arriving at the upper part of the region subject to the electro-magnetic fields than directed towards the peripheral regions of the liquid metal contained inside the blank, then in the opposite direction in order to return to its starting point (for example from top to bottom of the blank).

It will be understood that under these conditions there is obtained in the regions which are subject to the above-defined electro-magnetic fields, a circulation of metal according to which the liquid metal is caused to pass successively along the surface of the blank which has already solidified, then into the central region located in the vicinity of the axis of the solidifying blank.

Metallurgically, such a circulation of the liquid metal has very great advantages.

Firstly, this circulation of metal which is solidifying provides the advantage of spreading over a greater volume at the centre of the blank the inclusions which are contained in the solidifying metal, which avoids to a large extent the formation of inclusions located at the axis of the blank. This advantage is especially important in the case of continuous rotary casting, since there is produced in this case a combination of effects due to the circulation of the liquid metal and to the centrifugation resulting from the rotation. In fact, in continuous rotary casting, the inclusion particles, as well as the liquid metal, are subjected to a centrifugal force which tends to collect at the axis of the blank the inclusions which have a lesser density than that of the metal. According to the invention, due to the circulation currents which are created in the liquid metal, this collection of the inclusions towards the centre is effectively opposed, the inclusions thus being dispersed over a region of much greater volume and not causing the disadvantages which they produce when they are gathered along the axis of the product obtained.

The method according to the invention also has the advantage of allowing a more rapid and more homogeneous solidification of the central part of the blank.

In fact, in hitherto known methods, the solidification of the metal in the central part of the blank being formed takes place almost entirely by conduction, the heat from the liquid metal having to pass through the increasing thickness of the already solidified metal, the
outer surface of which is effectively cooled by water sprayed thereon.

Since, moreover, the liquid metal introduced into the mould has, by necessity to be at a slightly greater temperature than its solidification temperature so as to be supplied under satisfactory conditions, the result is that the solidifying metal must firstly give off the calories which correspond to its latent heat between its actual temperature and its solidification temperature.

Due to the circulation of the liquid metal which combines with the rotation according to the inventors, the liquid metal contained in the solidifying section of the blank is brought into contact with the wall which has already solidified. The result is that the liquid metal which was initially located at the centre of the blank and was thus at a higher temperature than its solidification temperature, causes a re-melting of the already solidified surface of the blank, thus losing a part of its heat, which causes a decrease in its temperature. Under these conditions, it is thus understood that, due to the circulation of the liquid metal inside the blank, on the one hand, the thickness of the already solidified wall is limited (which favours a good upper liberation of calories) and the temperature of the liquid metal which has to solidify is homogenized, with a lowering of the temperature of the liquid metal to the solidification temperature of possibly even below, the metal thus being in a state of unstable equilibrium, i.e. in the state of surfusion.

It will be understood that in these conditions since the whole mass of the liquid metal has been brought to its solidification temperature, or into a state where it is in surfusion, it will be possible to bring about its solidification in a much quicker manner than previously, the solidification taking place with a removal of a small amount of heat, and taking place quickly throughout the whole liquid mass.

Moreover, the method according to the invention makes it possible to eliminate effectively the solidifying bridges which occur during the final stage of solidification of the liquid metal, the bridges in question favouring the formation of pipes in the axis of the blank. Indeed it will be manifest that the circulation of liquid metal in the centre of the blank with the phenomena of re-melting of the already solidified metal, which have been described above make it possible to maintain a continuous liquid state over all the region where the end of solidification takes place, thus considerably reducing the risk of having isolated pockets of liquid metal which cause pipes.

The method according to the invention also makes it possible to obtain a modification of the crystalline structure of the section of the product obtained.

It is known, in fact, that in blanks obtained by continuous, rotary casting, there is obtained on the periphery a basaltic structure which results from the formation of solidification dendrites, whereas at the centre a crystallisation is obtained which is essentially equiaxed. By means of the invention it is possible to greatly reduce the importance of the basaltic structure in favour of the equiaxed structure, this phenomenon being probably due to the fact that the thickness of the solidified metal is reduced by bringing in a homogeneous manner, the solidifying metal to a temperature which is essentially the same at all its points and which is near to and even lower than its solidification temperature, which makes it possible to obtain a solidification of the metal which is close to a sudden solidification with a congealing “en masse”.

Moreover, it will also be noted that the fact of retaining, at a lower value, the thickness of the solidified wall at an instant when it is desired to remove calories from the liquid metal contained inside the blank (which combines with the rotation is advantageous from the thermic point of view, due to the obstacle to thermic exchanges constituted by the solidified part of the blank.

According to a preferred embodiment of the invention there is produced a first region of circulation of the liquid metal below the first cooling region by spraying which is located immediately after the mould or ingot mould.

According to the invention, it is also an advantage to provide two regions for the circulation of the liquid metal which are located between regions of intense cooling, the object of the first upper region for the circulation of liquid metal being to limit, and possibly even to reduce the already solidified thickness by providing the liquid metal with conditions which will permit its rapid and homogeneous solidification, the second, lower region for the circulation of the liquid metal being preferably located in the vicinity of the region which corresponds to the end of the solidification of the central part of the blank, the circulation of the liquid metal making it possible, at this location effectively to oppose the formation of solid bridges which cause the formation of pockets of liquid metal, which give rise to the creation of unwanted pipes.

Since the sole object of the electro-magnetic fields, which are provided according to the invention, is to ensure a circulation of the liquid metal, these magnetic fields preferably have a low frequency, for example, less than 100 cycles per second. In practice, it is an advantage to be able to use industrial 50 cycle current, but there is nothing against using, on the other hand, currents of lower frequency, for example, in the order of 5 to 20 cycles per second.

In order to obtain the desired effect, the currents passing through the inductors which are used must have very substantial intensities, for example of 2,000 to 10,000 amperes. It is due to such high intensities that it is possible to use voltages of the order of several volts which are applied to the terminals of the inductors.

Due to the existence of such low voltages, there is practically no risk of creating arcs between the inductors and the parts around them, and it is even possible to continue the cooling of the blank by spraying with water in the region of the inductors.

According to a preferred embodiment of the invention the apparatus which makes it possible to create electro-magnetic fields which ensure the circulation of the liquid metal is constituted by series of inductors constituted by copper plates of cylindric shape, which are stacked one on the other, with the interposition of an electrically insulating substance and having a good resistance to heat.

There may be used, for instance, as the insulating substance, the product sold under the trade name SIN-DANYO.

the inductors thus comprise a single turn, each turn being sputtered from the adjacent one by an insulating plate. In this way, each turn may be in the form of a cylinder, which facilitates the mechanical mounting of the inductors.
According to a preferred embodiment the cylindrical inductors may also have apertures of small diameter which allow the passage of nozzles ensuring the spraying of water for cooling, inside the inductor, against the surface of the blank, which has the effect of contributing further to the cooling of the blank which is solidifying, thus to the cooling of the inductors.

The direction of circulation of the liquid metal in the central part of the blank may be either from top to bottom or from the bottom to the top. Nevertheless, in the apparatus which ensures the circulation of the liquid metal in the vicinity of the part of the blank which is at the end of the solidification, it is preferably according to the invention, that the circulation of the liquid metal is such that the metal descends towards the bottom in its central region, in order to re-ascend on the periphery of the well of liquid metal in the vicinity of the solidified wall of the blank.

The invention is also the novel industrial process constituted by a bar of steel or similar metal obtained by the afore-described method, this bar having good metallurgical properties even along its axis, namely an absence of pipes and a good distribution of inclusions in a considerable volume of its central part, the peripheral region of solidification with the basaltic structure being reduced in favour of the central region of solidification with an equiaxed structure.

An embodiment of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

FIG. 1 is a diagrammatic view of apparatus for carrying out the invention;

FIG. 2 is a sectional view on a larger scale, of the apparatus according to the invention for ensuring the circulation of the liquid metal inside the blank;

FIG. 3 is a section on the line II—II of FIG. 1; and,

FIGS. 4 and 5 show diagrammatically two circuits for the electrical arrangements of the inductors according to the invention. There is shown diagrammatically in FIG. 1 a device for continuous, rotary casting. There can be seen in particular in the upper part a nozzle 1 which provides the stream 2 of liquid metal which serves for producing the blank. The beginning of solidification is ensured, by means of a mould or ingot mould 3, which, in the known manner, is cooled by circulation of water entering according to the arrows F1 and leaving according to the arrows F2. There is thus obtained the formation of an outer solidified skin 4 which retains the liquid metal 5 as it solidifies.

In known manner, the blank constituted by the skin 4 and the liquid metal 5 are guided by roller devices which ensure its retention in the axis of rotation and which permit its vertical downwards extraction.

With the aim of simplifying the drawings, these guiding and extraction rollers have not been shown.

Below the mould 3, the blank is subjected to intense cooling by means of water sprayed by jets 6 according to a known arrangement.

There is thus obtained a thickening of the skin of solidified metal with a corresponding decrease of the inner liquid metal. Simultaneously, there is a contraction of the outer diameter of the blank due to its cooling.

Below the cooling zone constituted by the spraying nozzles 6, there is provided, according to the invention, a device 7 which allows the creation of circulation currents in the liquid metal, as will be explained. Nevertheless, in FIG. 1 it will be noted that the presence of these circulation currents has the effect of keeping at a substantially constant value, the thickness of the wall, whereas a homogenisation and an overall decrease of the temperature of the liquid metal are obtained.

Below the inductor device 7 there is located a further cooling zone produced by means of spraying nozzles 8 which assure the spraying of water onto the outer surface of the blank. A more rapid solidification of the liquid metal 5 is obtained in this zone due to the homogenisation of the temperatures which were obtained in the vicinity of the inductor device 7, and due to the lowering of the average temperature of the liquid metal.

Below the cooling zone created by the spraying nozzles 8 there is provided, according to this embodiment of the invention, a second inductor device 9 which provides a second zone of axial circulation of the liquid metal. As has been diagrammatically shown in FIG. 1, this second region is located near the end of the solidification of the liquid metal. According to a preferred embodiment of the invention, the currents induced inside the liquid metal are such that the circulation of the metal takes place in a downwards direction, along the axis of the blank, and upwards along the surface of the solidified metal.

Finally, other spraying nozzles are provided below the inductor device 9 so as to be able to continue the cooling of the blank.

There is shown on a much larger scale on FIGS. 2 and 3, the current inductor device 7 of FIG. 1.

As can be seen in FIGS. 2 and 3, the inductor device 7 is constituted by three inductors 11, 12 and 13 which are separated from each other and which are retained by plates 14, 15, 16 and 17 of electrically insulating material and which are resistant to heat.

For ease of mounting, these insulating plates 14, 15, 16 and 17 have a square shape as can be seen in FIG. 3.

These insulators may, for example, be made of material sold under the trade name of SINDANYO.

As can be seen in FIGS. 2 and 3, the inductors 11, 12, 13 are identical. They are constituted by a flat bar of copper which is deformed so as to produce a single turn the ends 11a and 11b of which are separated by an insulator and connected to the source of current.

In the embodiment which is shown in FIGS. 2 and 3, the electrodes 11, 12, 13 are pierced by apertures in which are located spraying nozzles 19 which make it possible to spray the cooling water on the outer surface of the blank which passes inside the inductor device 7. This cooling water also makes it possible to keep the inductor as well as the insulating plates which separate them, at a relatively low temperature.

The inductor device which has been described may either by rotated at the same speed as the blank or may even be kept stationary, depending on the ease of mounting it on the device.

There is also shown in FIGS. 2 and 3 the skin 4 of solidified metal which contains the liquid metal 5 which is subjected to a stirring by circulation according to the invention.

There is also shown by arrows in FIG. 2, one direction of circulation of the liquid metal 5 according to which the metal flows downwards in the vicinity of the axis of the blank, while it reascends on the periphery.
along the inner surface of the skin of solidified metal. Naturally, it is the layout of the electrical connections of the inductors 11, 12 and 13 which determines the direction of circulation of the liquid metal.

There is shown in FIG. 4, the electrical diagram of the device which supplies the inductors 11, 12 and 13.

For this purpose, there is used a three-phase transformer connected to the three-phase R.S.T. system. There are schematically illustrated in FIG. 4 the three primary windings 20, 21 and 22 of the three-phase transformer, the secondary windings of which are, in the present case, constituted by the single turns 23, 24 and 25.

It would naturally be possible to use transformers whose secondary windings comprise a slightly greater number of turns. But it is an advantage to reduce to a minimum the number of turns of the secondary windings of the transformer, since one is trying to obtain a maximum voltage at the terminals of the inductors 11, 12 and 13.

As can be seen from FIG. 4, each turn of the secondary winding is connected to an inductor so as to create an electro-magnetic field which displaces vertically along the axis of the blank.

Naturally, this field is a pulsatary field which has the frequency of the three-phase system.

Due to this arrangement, there can be obtained by means of a three-phase system of 3,100 volts between phases an intensity passing through each of the inductors which is about 5 to 6,000 amperes at a voltage of about 1 volt.

Naturally, it would not be beyond the scope of the invention to replace the single turn inductors 11, 12 and 13 which have been described by inductors of conventional type which comprise a limited number of turns, for example, up to five turns.

There is shown in FIG. 5, the electrical supply diagram from a three-phase transformer for six inductors provided in two groups of three, the inductors being placed two by two in series in the circuit which connects them to the secondary winding of the transformer.

Under these conditions, it will be understood that there is obtained the same circulation effect of the liquid metal over a greater area of the blank.

It is also possible, without diverging from the scope of the claimed invention, to use inductors supplied with polyphase currents other than three-phase currents, for example, six-phase currents.

It can thus be seen that the invention makes it possible, in a very simple manner, to produce inside the solidifying liquid metal, circulation currents which develop vertically along the axis of the blank in order to combine with the rotation.

It is understood that the embodiments which have been described above have only been given as an example and that they may receive any desirable modifications without diverging from the framework of the invention.

In particular, it is clear that the number of inductor devices placed along a continuous casting line can vary, each inductor device can itself have different numbers of inductors, on condition that they induce an electro-magnetic field which ensures a displacement of the liquid metal. Similarly, the electric features which were given in the preceding description were only for illustrating certain possible embodiments, and it is known that these electrical features have to be adapted, in each particular case, depending in particular on the dimensions of the blank. Nevertheless, the characteristics of the electric currents applied to the inductors should be chosen so as to limit to the maximum the heating effects. For this, it is appropriate to choose low frequency currents.

Similarly, since the electrical effects are obtained substantially by the circulation of a high intensity of current in the inductors, it is preferable to supply the inductors in question with currents of very low voltage, which considerably simplifies the problems set by the insulation of the inductors and which makes it possible to have water-cooling at the level of the inductors without any danger.

What is claimed is:

1. A method of continuously casting metal by pouring molten metal into the upper end of a vertical mold while cooling said mold and rotating it about its vertical axis to form a casting from said metal, the improvement which comprises the step of utilizing an electro-magnetic field to establish an axial circulation of the molten metal, beneath said mold, only in a localized portion of the molten metal near the bottom of the molten metal pool in said casting, the direction of said axial circulation being towards the bottom in the central region of the pool and towards the top of the periphery of said pool.

2. A method according to claim 1 in which the circulation of the liquid metal is effected by the electro-magnetic field induced by a group of several inductors located at the periphery of the blank and each supplied by a phase of polyphase current.

3. A method according to claim 2, in which currents having an intensity of between 2,000 and 10,000 amperes are passed through the inductors.

4. A method according to claim 2, in which the inductors are supplied with a low voltage, for example, equal to several fractions of a volt or several volts.

5. A method according to claim 2 in which the polyphase current has a low frequency for example, less than 100 and preferably between 5 and 60 cycles per second.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,804,147 Dated 16 April 1974

Inventor(s) LOUIS BABEL and MICHEL MOLA

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

[30] Foreign Application Priority Data
April 2, 1970 France.............70 11959

Signed and sealed this 17th day of September 1974.

(SEAL)
Attest:

McCoy M. GIBSON JR. C. MARSHALL DANN
Attesting Officer Commissioner of Patents