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(54) IMPROVEMENTS IN OR RELATING TO A METHOD OF CONTINUOUSLY CASTING A STEEL STRAND AND APPARATUS THEREFOR

(71) We, VEREINIGTE ÖSTERREICHISCHE EISEN- UND STAHLWERKE- ALPINE MONTAN AKTIENGESELLSCHAFT, a company organized under the laws of Austria, residing at Vienna, Werksgelände 4010 Linz, Austria, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a method of continuously casting a steel strand having a length exceeding the length of a mould having a closed end, into which mould molten steel is introduced from a vessel, such as a tundish, and during the casting procedure the mould is moved away from the vessel along a substantially horizontal path to form a steel strand having a solidified hollow strand skin and a liquid core therein, further molten steel being poured from the vessel along the liquid core so that the further molten steel flows in the direction towards the closed end of the mould, as well as to apparatus suitable for carrying out this method.

A method of this kind and apparatus for carrying out the method is described and claimed in U.K. Patent No. 1316607, the method is disclosed in the publication by H. E. Allen, L. Watts and R. Hadden, "Horizontal Continuous Casting in a Closed-End Mold System, The Watts Process", Continuous Casting, Biarritz, France, May 30th to June 2nd, 1976 (publication of lectures at a Continuous Casting Convention).

The disadvantage of the known method is that the longer the casting is continued, the smaller the channel for supplying molten steel from the tundish to the continuous casting mould becomes, i.e. the diameter of the liquid core gradually reduces throughout the entire length of the strand. Thereby the length of the strand which can be produced by the known method is limited. It is a further disadvantage that the temperature falls so low because of the heat emission from the strand surface to the environment by radiation or cooling that it is below the liquidus temperature of the steel over a substantial part of the strand's longitudinal extension. This condition prevails anyway a short distance away from the outflow opening of the vessel, or tundish, and then, down to the closed end of the mould, a zone, with a two phase mixture of liquid melt and solidified crystals, is created. This zone, when the casting procedure has been finished, solidifies. The presence of the two-phase mixture over such a considerable length of the strand is a grave disadvantage since the solid/liquid mixture gradually becomes more semiliquid and a uniform supply of molten steel to the closed end of the mould is not ensured. Also, a uniform soldification and homogeneity of the cast strand is not ensured safe guarded with this known method of operation.

An object of the present invention is to improve this known method in such a way that it is not only possible to produce longer strands operationally safely, but also to obtain a qualitative improvement of the cast strand. In particular it is an object of the invention to create better conditions for the supply of molten steel to the mould and for the solidification of the strand.

According to a first aspect of the invention there is provided a method of continuously casting a steel strand using a mould having a closed end, the cast steel strand having a longitudinal extension exceeding that of the mould, said method comprising the steps of introducing molten steel from a vessel into said mould, moving said mould away from said vessel along a substantially horizontal path to form the steel strand comprising a solidified hollow strand skin and a liquid core therein, pouring further molten steel along said liquid core, which further molten steel flows in the direction towards the closed end of the mould, supplying heat to a major portion of the longitudinal extension of the strand located outside the mould, causing the liquid core said strand to have a substantially uniform temperature throughout the said major portion of the strand and regulating said temperature so that it is above the liquidus temperature of the steel throughout the said major portion of the cast strand.

It is particularly advantageous if the method further comprises the steps of establishing a first zone, a second zone and a third zone, arranged consecutively in the direction of movement of the mould, the first zone being disposed adjacent the casting vessel and the third zone adjacent the mould, with the second zone therebetween, the first and third zone being cooling zones and the said major portion of the strand lying substantially wholly within the second zone, maintaining the temperature of the liquid core of the strand substantially constant in the said second zone and causing the temperature of the liquid core to decrease from about the beginning, with respect to the direction of mould movement, of the third zone.

Advantageously, the temperature of the liquid core decreases to the liquidus temperature approximately at the end, with respect to the direction of mould movement, of the third zone and to below the liquidus temperature in or adjacent the mould.

For improving the quality of the strand, i.e. for improved mixing of the strand core which also effects a temperature equalization transversely and longitudinally of the strand, it is advantageous to administer a stirring movement to the liquid core of the strand simultaneously with supplying heat.

However, the method can also be applied in such a manner that the stirring movement of the liquid strand core occurs only in the third zone, which is disposed adjacent the mould.

A further way of doing this is that the stirring movement of the liquid strand core is carried out until the end of the casting procedure substantially only within the third zone, while in the remaining regions of the strand the stirring movement is only effected during solidification of the liquid core of the strand.

According to a second aspect of the invention there is provided apparatus for continuously casting a steel strand comprising a vessel for containing molten steel and having an outflow opening, a mould having a closed end, the mould being adapted to be capable of movement away from said vessel in a substantially horizontal direction to form a strand comprising a liquid core in solidified hollow strand skin and being longer than the mould, and a plurality of heating means adapted to be capable of enveloping the strand and movable into and out of operating position one after the other while the mould is substantially horizontally moved away and the steel strand forms.

Preferably, the heating means are electrical heating means and are combined with an electro-magnetic stirring means and which are successively movable into and out of the operation position during the course of movement of the mould i.e. during formation of the steel strand.

Suitably, a further electromagnetic stirring means is provided behind the mould, with respect to the direction of mould displacement, and is displaceable together with the mould.

The further electromagnetic stirring means may be provided with cross bores for introducing spraying nozzles for cooling the strand.

Furthermore, it is advantageous if the heating and the further stirring means are provided with supporting means engaging the lower side of the strand.

Advantageously, each of the heating means has a C or U-shaped cross-section, and is adjustable relative to a closure piece which itself may be movable into and out of the operating position, which closure piece is designed as heat-insulating plate.

Embodiments of the present invention shall now be described, by way of example only, and with reference to the accompanying drawings, wherein:—

Fig. 1 is a vertical section through a horizontal-type continuous casting apparatus according to the invention in a very simplified, schematic illustration,

Fig. 2 shows the course of the temperature in the liquid core of the strand according to the prior art,

Fig. 3 is a similar illustration, but for the course of the temperature when applying the method according to the present invention, and

Fig. 4 is a vertical section along line IV–IV of Fig. 1 on an enlarged scale.

In Fig. 1, a tundish is denoted by 1, from which tundish molten steel 2 flows through a nozzle and a hollow starter piece 3 into a water-cooled mould 4. This mould 4 has a closed end 5 and, when pouring is first started, it overlaps the starter piece 3. The mould 4 carries out an oscillating movement in a horizontal direction and is moved away from the tundish 1, thus forming a strand 6, which has a solidified hollow strand skin 7 and a liquid core 8. To be moveable, the mould 4 is mounted on a car 9, which is continuously displaced along a rail path 10 in the direction of the arrow 11. Boundaries of a first zone are denoted by 12 and 13, this zone being a cooling zone, in which cooling zone spraying nozzles 14 are provided, the boundary 13 being indicated in broken lines. According to the prior art process, it is approximately at the position of boundary 13 where the first zone ends, which cooling zone directly follows the starter piece 3 and prevents the occurrence of either too pronounced an erosion of the strand skin caused by the continuously flowing steel, or a break-through of the strand skin 7. The boundary of the first zone, when using the method of the invention however, is denoted by 13^1 rather than 13. According to the invention, there is an attempt to reduce the cooling effect in this zone so that the temperature decrease is only slight, whilst the temperature of the liquid core 8 is to be as near the temperature in the tundish 1 as possible, which temperature in the tundish is considerably above the liquidus temperature of the steel 2.

A further boundary is denoted by 15. In the prior art method, in the zone between the lines 13 and 15, heat had been conducted away by radiation and the temperature of the liquid core 8 had decreased. According to the present invention, however, combined heating and stirring units 25, 26 and 27 are provided within the second zone delimited by the boundaries 13^1 and 15, which units are described in detail hereinbelow.

Immediately before the mould 4, relative to the casting direction 11, there is a third zone, which is another cooling zone and is defined by boundaries 15 and 16 and has spraying nozzles 17. Cooling of the strand begins roughly near the boundary 15. Despite the cooling effect of the mould 4, the liquid core 8 is enlarged in this area as is shown in the drawing, wherein the boundary 18 indicates the end of the strand. The strand is liquid adjacent the closed end 5 of the mould 4, because the end 5 receives directly the liquid core, which cools to form the strand skin that thickens towards the open end of the mould and the third zone.

From Fig. 2 it can be seen that with the method used hiterto, the temperature distribution of the liquid core 8 throughout the length of the strand 6 is as represented by the curve 21. In the first, cooling, zone defined by boundaries 12 and 13, the temperature falls steeply to the liquidus temperature 20, and it then falls gradually to a temperature below the liquidus temperature, so that a temperature between the solidus temperature 19 and the liquidus temperature 20 prevails at the closed end 5 of the mould. Consequently, a two phase mixture of solid/liquid exists in the whole region between the boundaries 13 and 18, which is very disadvantageous as movement of the steel is obstructed and the solidification is adversely affected.

Fig. 3 shows the temperature distribution in the core 8 according to a preferred embodiment of the present invention. In the shorter first cooling zone indicated by the lines 12, 13^1, the temperature decrease is relatively slight. In the second zone following thereupon, the temperatue remains substantially constant, as is shown by the temperature curve 22, and it is well above the liquidus temperature so that premature formation of mixed crystals, or dendrites, is reliably avoided. Only in the third zone, between boundaries 15 and 16 and following the second zone, does the temperature decrease to approximately, and in the special, illustrated, case exactly, the liquidus temperature 20. As a result, the formation of a two-phase mixture is limited to approximately the cooling region between the boundaries 16 and 18 in the mould 4. Before this mould region 16 to 18, an electromagnetic stirring apparatus is arranged, whose function and effect on the improvement of the quality of the continuous casting is known *per se* (see "Die erste electromagnetische Rühranlage für Stranggub" ("The first electromagnetic stirring plant for continuous casting") by IRSID and CEM as well as publication by Robert Alberny, Lazlo Backer, Jean-Pierre Birat, Paul Gosselin, and Maurice Wanin "Quality Improvement of Strand-cast Billets Through Electromagnetic Stirring", Electric Furnace Proceedings, 1973, pages 237 to 245). In the drawings this apparatus is illustrated only schematically and denoted by 23 as a whole. It is provided with bores 24 for the arrangement of spray of jet nozzles 17 for cooling the strand 6, the lower openings serving to drain the water. Heating units are denoted by 25, 26 and 27, which heating units can be designed in different ways. In particular the heat supply can be effected electrically by radiation, but also could be effected by oil or gas heating by radiation and convection. It is preferred, however, to use combined electric and electromagnetic heating and stirring. The effect is that the strand skin is maintained at a uniform temperature, so that the temperature of the liquid core 8 approximately follows the curve 22 of Fig. 3. The heat supplied by the units 25, 26 and 27, which are moved one after the other towards the strand 6, as described below, is regulated by temperature measuring equipment and/or measuring equipment for the thickness of the strand skin (not shown). Simultaneously, when casting (i.e. while molten steel is being poured along the liquid core 8), or when casting of the strand has finished, a stirring movement is effected in the liquid core 8, as is known *per se* and has been disclosed in detail in the publications mentioned. It is therefore unnecessary, to discuss the construction details of these means which belong to the prior art and have frequently been used in the field of continuous casting.

Fig. 4 illustrates one of a number of possibilities for moving the heating and stirring units 25, 26 and 27 to surround the strand 6 which itself is being formed without changing its position.

For each one of these units 25, 26 and 27, a roller bank 28 is provided laterally of the strand and leads to a further roller bank 28^1, which is adjacent the strand 6. The roller bank 28^1 is adjustable relative to the units 25, 26 and 27 by lifting or pivot means not illustrated, or a displacement means 29 displaces each of the units 25, 26 and 27 one after the other on the roller bank 28^1, supports 30 serving to support the strand 6. When the strand has been cast the roller bank 28^1 is lowered in the direction of the arrows 31. The heating and stirring units 25, 26 and 27 are provided with cooling water connections 32 for the electromagnetic stirring means and with a current supply conduit 33, and the units have, particularly for casting slabs, a C or U-shaped cross-section. They are movable relative to a heat-insulating wall 34 so that a closed space is formed. The wall 34 is on mounts 35 so as to be horizontally displaceable. When the strand has been fully cast, the units 25, 26 and 27 are removed in the direction of the arrow 36, the strand is divided in a number of parts in a usual manner and further processed. Of course, the units 25, 26 and 27 can have other forms of cross-section and be designed in a number of parts. Movement of the units towards the strand 6, too, can be effected in other ways, for instance by horizontally displacing the units using rollers on carriers having an I cross-section and arranged above the strand 6 and transversely to the direction of movement 11 of the mould.

The stirring means 23 also is provided with supports 30 for the strand 6. In contrast to the heating and stirring units 25, 26 and 27, it is closed on all sides and, this has a cross-section adapted to the strand profile. The stirring means 23 is mounted on the car 9 and is already in an operating position when the continuous casting apparatus is first put in operation. If it is advantageous, it can also reciprocate together with the mould 4 in the direction of movement 11.

Due to the heat supply, the diameter of the liquid core 8 can be kept wider than has hitherto been possible, and strands of unlimited length and of the best quality can be produced, insofar as a corresponding number of units 25, 26 and 27 is available. Each of these units is designed to be alike, i.e. they form a modular construction system, which lowers the investment and operating costs.

WHAT WE CLAIM IS:—

1. A method of continuously casting a steel strand using a mould having a closed end, the cast steel strand having a longitudinal extension exceeding that of the mould, said method comprising the steps of introducing molten steel from a vessel into said mould, moving said mould away from said vessel along a substantially horizontal path to form the steel strand comprising a solidified hollow strand skin and a liquid core therein, pouring further molten steel along said liquid core, which further molten steel flows in the direction towards the closed end of the mould, supplying heat to a major portion of the longitudinal extension of the strand located outside the mould, causing the liquid core of said strand to have a substantially uniform temperature throughout the said major portion of the strand and regulating said temperature so that it is above the liquidus temperature of the steel throughout the said major portion of the cast strand.

2. A method as claimed in Claim 1, further comprising the steps of establishing a first zone, a second zone and a third zone, arranged consecutively in the direction of movement of the mould, the first zone being disposed adjacent the vessel and the third zone adjacent the mould, with the second zone therebetween, the first and third zones being cooling zones and the said major portion of the strand lying substantially wholly within the second zone, maintaining the temperature of the liquid core of the strand substantially constant in the said second zone and causing the temperature of the liquid core to decrease from about the beginning, with respect to the direction of mould movement, of the third zone.

3. A method as claimed in Claim 2, wherein the temperature of the liquid core is caused to decrease to the liquidus temperature approximately at the end, with respect to the direction of mould movement, of the third zone.

4. A method as claimed in Claim 2 or 3, wherein the temperature of the liquid core is caused to decrease to below the liquidus temperatue in or adjacent the mould.

5. A method as claimed in any preceding claim, further comprising the step of stirring the liquid core of the strand simultaneously with the step of supplying heat.

6. A method as claimed in Claim 5, further comprising the step of establishing a first zone, a second zone and a third zone, arranged consecutively in the direction of movement of the mould, the first zone being disposed adjacent the vessel and the third zone adjacent the mould, with the second zone therebetween, the first and third zones being cooling zones and the said major portion of the strand lying substantially wholly within the second zone, and wherein the liquid core of the strand is stirred only in said third, cooling zone.

7. A method as claimed in Claim 5, further comprising the step of establishing a first zone, a second zone and a third zone, arranged consecutively in the direction of movement of the mould, the first zone being disposed adjacent the vessel and the third zone adjacent the mould, with the second zone therebetween, the first and third zones being cooling zones and the said major portion of the strand lying substantially wholly within the second zone, and wherein the liquid core of the strand is stirred substantially within said third cooling zone until the step of pouring further molten steel along the liquid core has ceased and the liquid core in the

second zone is stirred only while the core is solidifying.

8. Apparatus for continuously casting a steel strand comprising a vessel for containing molten steel and having an outflow opening, a mould having a closed end, the mould being adapted to be capable of movement away from said vessel in a substantially horizontal direction to form a strand comprising a liquid core in a soldified hollow strand skin and being longer than the mould, and a plurality of heating means adapted to be capable of enveloping the strand and movable into and out of operating position one after the other while the mould is substantially horizontally moved away and the steel strand forms.

9. Apparatus as claimed in Claim 8, wherein the vessel is a tundish.

10. Apparatus as claimed in Claim 8 or 9, wherein the plurality of heating means are electrical heating means, the apparatus further comprising stirring means combined with said electrical heating means.

11. Apparatus as claimed in Claim 10, in which the stirring means is electromagnetic.

12. Apparatus as claimed in Claim 10 or 11, wherein further stirring means, which is electromagnetic, is provided behind the mould, with respect to the direction of mould displacement, and is displaceable together with the mould.

13. Apparatus as claimed in Claim 12, wherein said further stirring means is provided with cross bores, spraying nozzles being introduced in said cross bores for cooling the strand.

14. Apparatus as claimed in Claim 12 or 13 wherein the heating means and the further stirring means are provided with supporting means for engaging the lower side of the strand.

15. Apparatus as claimed in any of claims 8 to 14, wherein said plurality of heating means each has a C-shaped cross-section, the apparatus further comprising a closure part in the form of a heat-insulating plate, which closure part is movable into and out of operating position, the position of said heating means being adjustable relative to said closure part.

16. Apparatus as claimed in any of Claims 8 to 14, wherein said plurality of heating means each has a U-shaped cross section, the apparatus further comprising a closure part in the form of a heat-insulating plate, which closure part is movable into and out of operating position, the position of said heating means being adjustable relative to said closure part.

17. A method substantially as hereinbefore described with reference to Figures 1, 3 and 4 of the accompanying drawings.

18. Apparatus substantially as hereinbefore described with reference to Figures 1, 3 and 4 of the accompanying drawings.

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1584397 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG.1

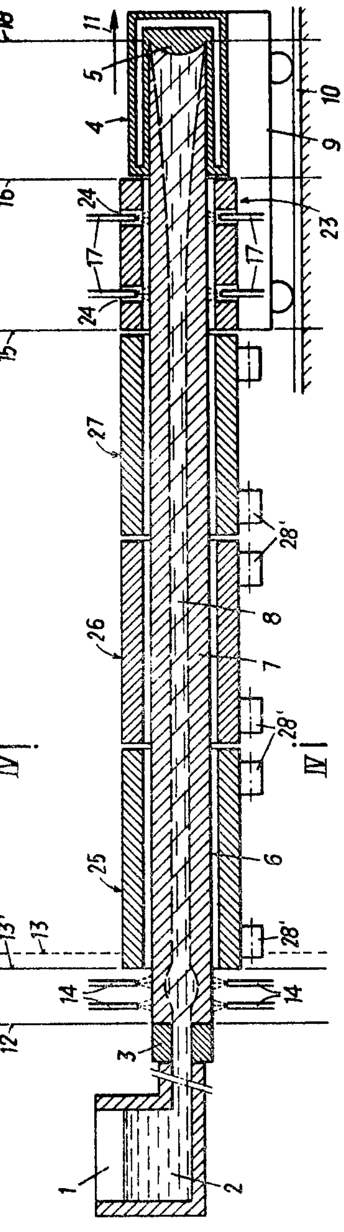

FIG.2

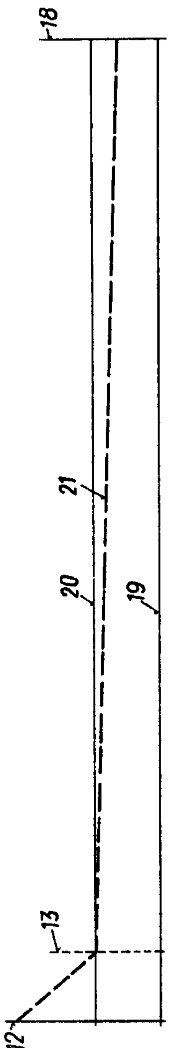

FIG.3

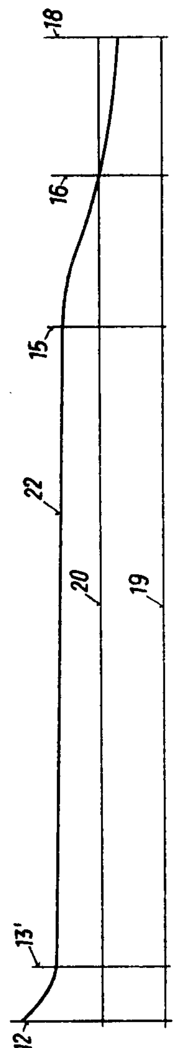

FIG. 4