METHOD AND APPARATUS FOR CONTINUOUSLY CASTING AND ROLLING METAL

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ABSTRACT OF THE DISCLOSURE

A method and apparatus for the processing of molten metal, by passing same at a controlled rate through a circulating liquefied cooling medium, to produce solidified metal of uniform temperature suitable for direct rolling without the necessity for any reheating. The method of the invention substantially eliminates heat exchange at outside surfaces, thereby enabling internal heat exchange to take place between solidified droplets and condensed liquid or steam and so avoids the colder and harder skin which is formed in conventional methods.

The present invention relates to the processing of molten metals, both of ferrous and non-ferrous metals, and more particularly to the processing of such metals between the molten and rolled stages and between molten and solidified or hot-working stages.

The conventional processing of molten metals, such as steel, requires the use of much heavy equipment which is very expensive both to install and to operate. Thus in the conventional ingot casting of molten steel to form sheets or other rolled forms the molten steel is first cast into ingot moulds, the ingots, after removal from the moulds, are heated in soaking pits and thereafter rolled in bloom mills to form blooms or slabs. The blooms or slabs are then reheated in a furnace and subsequently rolled into sheets or other forms which then normally require descaling and other surface treatments in order to obtain the finished product. In the known continuous casting process the molten steel is continuously cast into a water-cooled bottomless copper mould and continuously withdrawn therefrom in the form of slab or bloom. After withdrawal the slab or bloom—still containing a liquid core—is further cooled by water-spray, then air cooled, then either cut to length and follows the conventional bloom reheating and rolling, or bent to horizontal, re-heated, descaled and rolled in a continuous rolling equipment. In both cases the solidification of molten steel begins at the outer surface at a fast rate and progresses towards the centre at gradually reduced speed. This typical pattern of solidification causes heterogenous structure in the solidified metal due to differential crystallization and segregation. At the same time stresses develop due to shrinkage of the surface, such stresses often producing cracks in the solidified steel which may lead to the rejection of semi-finished or finished product. In both ingot casting and continuous casting process the solidified steel contains gases which is undesirable.

The object of the present invention is to provide a simplified method and apparatus for the processing of metals between the molten and rolled stages to produce rolled metals which have a structure and surface of superior quality.

A more particular object is to provide a method for the processing of molten metals, and an apparatus for carrying out such method, which enables the molten metal to be solidified without the formation of a hard skin thereon and which furthermore prevents oxidation of the metal being processed.

A still more particular object is to provide a method of processing molten metal, and an apparatus for carrying out such method, which enables molten metal to be continuously processed from the molten state to the finished, rolled state, without requiring the molten metal to be cast into ingots, blooms or slabs and without requiring reheating and descaling.

According to one aspect of the invention there is provided a method of processing molten metal comprising the steps of charging the molten metal to a tundish, discharging the molten metal from said tundish into a container in the form of one or more substantially vertical streams, subjecting said one or more streams to a sub-atmospheric pressure in the upper portion of said container with the stream or streams thereafter passing through a liquid cooling medium in said container, and delivering the metal from said container to a receptacle wherein the mixing streams form solidified metal of uniform temperature suitable for direct rolling.

The invention also provides apparatus for carrying out the above-defined method which comprises a tundish having an inlet for molten metal and one or more stoppered nozzles each forming a controlled outlet from the under-side thereof; a substantially upright container connected to said tundish beneath said one or more stoppered nozzles, said container being charged with a liquefied cooling medium; means for maintaining a sub-atmospheric pressure in said container; means for controlling the temperature in the cooling medium; and a receptacle having an entry connected to a discharge outlet from said container.

The apparatus of the present invention will now be more particularly described in relation to a preferred embodiment thereof which is illustrated in the accompanying drawings.

In the drawings:

FIGURE 1 is a side elevation in section; and
FIGURE 2 is a section through the line A—A of FIGURE 1.

In the embodiment illustrated the apparatus comprises a refractory tundish 1 which is covered with an insulating refractory lid 2 in order to reduce heat losses. An inlet 3, for receiving a supply of molten metal from a suitable source thereof (not shown), is mounted in lid 2 and a slag retaining wall 4 is provided within tundish 1.

In the base of the tundish 1 there are a number of discharge nozzles 5 widening at the bottom to promote dispersion of molten metal, three such nozzles being shown in the drawings, each of which has an adjustable stopper 6 for controlling the discharge of molten metal.

Mounted beneath tundish 1 is a cooling medium container 7 portion of which is enclosed within a housing 8.
At the top of container 7 is an inlet 9 having a screw conveyor 10 mounted therein for feeding the cooling medium in powdered form to the container. Container 7 is shaped to provide a vertical central passage 11, the upper and lower ends of which are connected together by means of a pair of symmetrically spaced lateral passages 12. A motor 13, driven by an externally mounted motor 14, is provided in each lateral passage 12 for circulating the cooling medium in a direction such that the cooling medium flows upwardly through central passage 11 countercurrent to the flow of molten metal. One or more heaters 15 are provided for melting the cooling medium at the start of operations and a number of water sprays 16 are provided within housing 8 for controlling the temperature of the cooling medium while the process is in operation. Housing 8 is also provided with a vapor outlet 17 and a cooling water drain 18.

A discharge trough 19 is mounted in the upper portion of container 7 and has openings in the bottom therethrough of each of which is directly underneath one of the discharge nozzles 5, with the openings being located directly over the central passage 11 of container 7 so that the molten metal will be discharged into this passage. As can be seen from FIGURE 2 the central opening of discharge trough 19 is arranged to discharge molten metal in the form of a continuous stream 30 while the outside openings are each arranged to discharge molten metal in the form of streams of dispersed droplets 31. An outlet 26, for connection to a vacuum pump (not shown), is also provided at the upper end of container 7 in order that a sub-atmospheric pressure may be maintained in the upper portion of container 7 during operation of the process.

At the lower end of container 7 there is mounted an elongated receptacle 21, having a continuous opening 22 therethrough, for collecting the metal which falls through the cooling medium. At the top of opening 22 a level control instrument 24 for automatic adjustment of the speed of rolls 26, and an outlet 25 for cooling medium and flush out cleaning are provided. An induction heater 23 is provided around the upper portion of receptacle 21 for the purpose of maintaining a seal of molten metal as will be more fully explained hereinafter. At the lower end of receptacle 21 there is mounted a pair of reduction rolls 26 which continuously withdraw metal in solidified form from the bottom of opening 22 and roll it into a sheet which is then passed through guide 27, guide rolls 28 (which can be driven if necessary) and then to a cooling trough 29. To allow for the spread of the steel during rolling the outlet of opening 22 adjacent the side of rolls 26 is widened out as shown in FIGURE 2. The reduction rolls 26 each consist of a cast steel mandrel which carries a heat resistant sleeve, with the sleeve being cooled from inside by the circulation of cooling water in grooves cut in the surface of the mandrel.

The operation of the above-described apparatus will now be described in relation to the processing of molten steel, it being understood however that this particular metal is merely given by way of illustration and that other molten metals can equally well be processed by the process and apparatus of the invention. In the following description it will be assumed that the apparatus is already in continuous operation with the cooling medium in contact with the metal in liquid form and being circulated by propellers 13, a seal of molten steel being maintained at or near the mouth of receptacle 21 and solidified steel being continuously withdrawn and rolled into a sheet by reduction rolls 26.

Molten steel of conventional or higher pouring temperature is continuously supplied to turret 1 through inlet 3 and is discharged through nozzles 5 into discharge trough 19. From the openings in the bottom of discharge trough 19 three streams of molten steel issue and pass downwardly through central passage 11 of container 7 in countercurrent to the flow of cooling medium. The central stream of molten steel, which comprises about 1/3 of the discharge from the trough 19, is in the form of continuous streams which pass through the cooling medium without being solidified, whilst the outer two streams are dispersed into the form of droplets which, owing to their greater specific surface and slower rate of fall, will be partially or completely solidified by the time they reach receptacle 21. A sub-atmospheric pressure is maintained in the upper portion of container 7 to degas the molten steel issuing from discharge nozzles 5 and to aid in dispersing the steel to increase the cooling therefrom.

In the upper portion of receptacle 21, a seal of molten steel is maintained, by means of induction heater 23 and the continuous supply of molten steel from the central stream from discharge trough 19, to prevent entry of the liquid cooling medium into the receptacle 21 and so prevent the contamination of the finished rolled product by the cooling medium. It is preferred that the induction heater 23 be a two frequency heater which sets up a flow of molten steel within the seal which aids the downward passage of the solidified droplets therethrough and also counteracts any turbulence created by the falling stream of molten metal. In the receptacle 21 four layers of steel are continuously formed from the falling streams, these layers having the following compositions from top to bottom:

(i) a liquid metal seal 32 through which solidified droplets are continuously sinking;
(ii) a layer 33 consisting of settled solidified drops in molten steel, the latter being continuously cooled and in the process of solidification by heat loss to the solidified droplets;
(iii) a layer 34 of homogenous, uniform temperature, solidified steel; and
(iv) steel 35 which is being further cooled by the reduction rolls 26 and continuously hot rolled thereby to form a finished sheet 36.

The degree to which the metal droplets are cooled during their passage through the cooling medium can be varied by adjusting the temperature of the cooling medium by use of the water sprays 16 and also by varying the rate of circulation of the cooling medium by varying the speed of propellers 13.

The cooling medium which is used in container 7 should be of neutral or preferably acid characteristics with regard to the metal being processed, should have low viscosity at the operating temperature and should not "wet" the metal being processed. For practical reasons regarding heat exchange the cooling medium should preferably have a high specific heat, a melting point reasonably low compared with that of the metal being processed, and a high boiling point. A suitable cooling medium, particularly for use with molten steel, is one comprising a mixture of Na₂O, BeO and SiO₂; a particularly preferred composition being 21% Na₂O, 45% BeO and 34% SiO₂ which composition has a melting point of 600° C.

The use of a cooling medium having the above-mentioned characteristics enables the molten metal being processed to be cooled gradually and uniformly, consequently, as no heat exchange (or very little) takes place through the walls of the receptacle, the steel processed has no hard skin of lower temperature through the core and is ideal for direct rolling. As the whole process from teeming to rolling is carried out substantially in the absence of oxygen, oxidation of the metal is practically completely eliminated.

The apparatus and process as above-described may be modified in various ways. Thus the number of outlets from discharge trough 19 may be varied and also the number of outlets forming continuous streams of molten metal and the number of outlets forming dispersed droplets can be varied to vary the ratio between molten metal and solidified droplets reaching receptacle 21.
In a further modification all outlets from discharge trough 19 can be arranged to form streams of dispersed droplets, in which case no liquid metal seal is provided so that induction heater 23 can be dispensed with, the separation of metal and cooling medium being achieved by the difference in their specific gravities with any cooling medium which is occluded in the solidified metal being expressed therefrom during the process.

In a still further modification the reduction rolls 26 can be replaced by withdrawal rollers, the opening between which is substantially the same as the width of the bottom opening in receptacle 21, so that the solidified metal is merely withdrawn from receptacle 21 in the form of sheets of metal without appreciable reduction in thickness thereof.

When it is necessary to start the process off from the beginning, for example when restarting after a prolonged shut-down, a dummy plate is first inserted between rolls 26 and container 7 and receptacle 21 are thereafter filled to the desired level with powdered cooling medium which is fed in by means of screw conveyor 10. The cooling medium is then melted by means of heater(s) 15, tundish 1 preheated to a temperature of about 1100° C. by means of a gas or oil burner, the propellers 13 are started to circulate the molten cooling medium and discharge means of stoppers 6. The vacuum pump is then started and the pressure in container 7 adjusted to a safe level, to prevent exhausting of the cooling medium, tundish 1 is then filled to operating level with molten steel and the stoppers 6 thereafter raised to open discharge nozzles 5, with water sprays 16 being turned on as required. Thereafter the pressure in container 7 is gradually reduced, the rolls 26 started at reduced operating speed a short while, for example 30 seconds, after opening discharge nozzles 5 and the induction heater 23 turned on. Then as steel in receptacle 21 reaches the operating level the pressure in container 7 can be reduced to the working level and the speed of rolls 26 adjusted to keep the level of steel in receptacle 21 steady.

For short interruptions in the operation it is only necessary to release the vacuum from container 7, close nozzles 5, stop sprays 16 and stop the rolls 26 when the top of the steel is within the bite thereof. For longer shut-downs it is necessary to empty tundish 1, release the vacuum from container 7 and to thereafter drain the cooling medium from container 7 through discharge opening 25.

The apparatus of the present invention has the very great advantage of eliminating much of the apparatus presently used in conventional steel making processes thereby resulting in a much smaller space requirement for plant of a given capacity, lower capital cost and smaller operating labour costs. The power requirements are also considerably reduced by the elimination of soaking pits, reheating furnaces, descaling, bending etc. plant, while the rolling expenses are reduced to a minimum because the present process requires only a small rolling reduction ratio and the rolling takes place while the steel is in a more plastic state than with presently used equipment.

There is also a complete elimination of scale losses, due to the protective action of the cooling medium, and an absence of reject due to various defects in ingots or slabs as produced in conventional processing of steel and other metals.

What we claim is:

1. A method of processing molten metal comprising the steps of charging the molten metal to a tundish; discharging the molten metal from said tundish into a container in the form of at least one substantially vertical stream; circulating a cooling medium in said container, said cooling medium being one which does not wet the metal, is of neutral characteristics with respect to the metal and has a low viscosity at the temperature of operation; subjecting said at least one stream to a sub-atmospheric pressure in the upper portion of said container and thereafter passing said at least one stream in countercurrent relationship and at a controlled rate through the liquified cooling medium circulating within said container; and delivering the metal from said container to a receptacle wherein the metal from said at least one stream mixes to form solidified metal of uniform temperature suitable for direct rolling.

2. A method of processing molten metal comprising the steps of charging the molten metal to a tundish; discharging the molten metal from said tundish into a container in a plurality of substantially vertical streams; circulating a cooling medium in said container, subjecting said streams to a sub-atmospheric pressure in the upper portion of said container and thereafter passing said streams through the liquified cooling medium in said container, the metal in at least one of said streams being dispersed into the form of droplets which at least partially solidify during their passage through said cooling medium with the metal in another of said streams being in the form of a continuous stream which is maintained in the molten state during its passage through said cooling medium; and delivering the metal from said container to a receptacle wherein the metal from said streams mixes to effect cooling and solidification of said metal by heat transfer between said molten metal and said at least partially solidified droplets with virtually no heat exchange occurring between said receptacle and the metal from said streams to thereby form solidified metal of uniform temperature suitable for direct rolling, the molten metal from said another of said streams serving to maintain a molten metal seal at the top of said receptacle to prevent entry of cooling medium into said receptacle.

3. A method of processing molten metal according to claim 2, wherein said seal is heated to maintain same in the molten state.

4. A method of processing molten metal according to claim 3, wherein the heating of said seal sets up a circulation of the molten metal therein which aids the downward passage of said at least partially solidified droplets through said seal and counteracts turbulence created by the continuous stream of molten metal.

5. A method of processing molten metal comprising the steps of charging the molten metal to a tundish; discharging the molten metal from said tundish into a container in a plurality of substantially vertical streams; circulating a cooling medium in said container, said cooling medium being one which does not wet the metal, is of neutral characteristics with respect to the metal and has a low viscosity at the temperature of operation; subjecting said streams to a sub-atmospheric pressure in the upper portion of said container and thereafter passing said streams in countercurrent relationship and at a controlled rate through the liquified cooling medium circulating within said container, the metal in each of said streams being dispersed into the form of droplets which at least partially solidify during their passage through said cooling medium; and delivering the metal from said container to a receptacle wherein the metal from said streams is collected in the form of solidified metal suitable for direct rolling.

6. A method of processing molten metal comprising the steps of charging the molten metal to a tundish having three aligned discharge nozzles in the bottom thereof; discharging the molten metal through said discharge nozzles into a dispersion trough having three openings in the bottom thereof with each of said openings being located beneath one of said discharge nozzles; circulating a cooling medium in said container, said cooling medium being one which does not wet the metal, is of neutral characteristics with respect to the metal and has a low viscosity at the temperature of operation; discharging the molten metal through said openings into a container in the form of three substantially vertical streams; subjecting said
streams to a sub-atmospheric pressure in the upper portion of said container and thereafter passing said streams through the body of liquefied cooling medium in said container, the metal in the outer ones of said streams being dispersed into the form of droplets which at least partially solidify during their passage through said cooling medium; and delivering the metal from said container to a receptacle wherein the metal from said streams mixes to form solidified metal of uniform temperature suitably solidifying for direct rolling, the solidified metal from said central one of said streams serving to maintain a molten metal seal at the top of said receptacle to prevent entry of cooling medium into said receptacle.

7. A continuous method of processing molten metal comprising the steps of continuously charging the molten metal to a tundish having three aligned discharge nozzles in the bottom thereof; continuously discharging the molten metal through said discharge nozzles into a dispersion trough having three openings in the bottom thereof with each of said openings being located beneath one said discharge nozzle; continuously discharging the molten metal through said openings into a container in the form of three substantially vertical streams; circulating a cooling medium in said container, said cooling medium being one which does not wet the metal, is of neutral characteristics with respect to the metal and has a low viscosity at the temperature of operation; subjecting said streams to a sub-atmospheric pressure in the upper portion of said container thereafter passing said streams through the body of liquefied cooling medium in said container, the metal in the outer ones of said streams being dispersed into the form of droplets which at least partially solidify during their passage through said dispersing medium with the metal in the central one of said streams being in the form of a continuous stream which is maintained in the molten state during its passage through said central cooling medium; and continuously delivering the metal from said container to an elongated upright receptacle having an open-ended passage extending thereinto wherein the metal from said streams mixes to form solidified metal of uniform temperature, the solidified metal from said central one of said streams serving to maintain a molten metal seal at the top of said receptacle and to provide an entry connected to a discharge outlet from said container.

8. Apparatus for processing molten metal comprising a tundish having an inlet for molten metal and at least one stopper controlled outlet nozzle in the underside thereof; a substantially upright container connected to said tundish beneath said at least one outlet nozzle, said container being charged with a liquefied cooling medium; means for maintaining a sub-atmospheric pressure in said container; controllable means for circulating liquefied cooling medium through said container in such manner that said cooling medium flows upwardly through that portion of said container located beneath said at least one outlet nozzle; means for controlling the temperature of said cooling medium; and a receptacle having an entry connected to a discharge outlet from said container.

9. Apparatus for processing molten metal according to claim 8 wherein said receptacle comprises an elongated receptacle having an open-ended passage extending therethrough and withdrawal rolls mounted adjacent the bottom opening of said receptacle, said withdrawal rolls being adapted to support solidified metal contained in said receptacle and to withdraw and cool said solidified metal.

10. Apparatus for processing molten metal according to claim 9 wherein said rolls are reduction rolls adapted to roll the solidified metal into a sheet.

11. Apparatus for processing molten metal comprising a tundish having an inlet for molten metal and a plurality of stopper controlled outlet nozzles in the underside thereof; a substantially upright cooling medium container connected to said tundish beneath said outlet nozzles, said container comprising a casing having a substantially vertically disposed central passage located beneath said outlet nozzles, each of said plurality of openings being adapted to discharge molten metal issuing therefrom into a stream of dispersed droplets, the outer ones of said openings being adapted to discharge molten metal in the form of a continuous stream; means for maintaining a sub-atmospheric pressure in said container; electrical heater means for liquifying cooling medium in said container; means for controlling the temperature of said liquefied cooling medium; and a receptacle having an entry connected to a discharge outlet from said container.

12. Apparatus for processing molten metal comprising a tundish having an inlet for molten metal and three aligned stopper controlled outlet nozzles in the underside thereof; a substantially upright cooling medium container connected to said tundish beneath said outlet nozzles, said container comprising a casing having a substantially vertically disposed central passage located beneath said outlet nozzles, each of said plurality of openings being adapted to discharge molten metal issuing therefrom into streams of dispersed droplets with the central one of said openings being adapted to discharge molten metal in the form of a continuous stream; means for maintaining a sub-atmospheric pressure in said container; electrical heater means for liquifying cooling medium in said container; means for circulating liquefied cooling medium through said container; water spray means for controlling the temperature of said liquefied cooling medium; an elongated upright receptacle having an open-ended passage extending thereinto connected to a discharge outlet at the lower end of said container; rolls for withdrawing solidified metal from said receptacle mounted adjacent the lower end thereof.

13. Apparatus for processing molten metal comprising a tundish having an inlet for molten metal and a plurality of stopper controlled outlet nozzles in the underside thereof; a substantially upright cooling medium container connected to said tundish beneath said outlet nozzles, said container comprising a casing having a substantially vertically disposed central passage located beneath said outlet nozzles, each of said plurality of openings being adapted to discharge molten metal issuing therefrom into a stream of dispersed droplets, each of said plurality of openings being adapted to discharge molten metal issuing therefrom into a stream of dispersed droplets, means for maintaining a sub-atmospheric pressure in said container; electrical heater means for liquifying cooling medium in said container; means for circulating liquefied cooling medium through said container; means for controlling the temperature of said liquefied cooling medium; and a receptacle having an entry connected to a discharge outlet from said container.

14. A method of processing molten metal as claimed in claim 1 wherein said receptacle is an elongated, upright receptacle having an open-ended passage extending therethrough, and the method further comprising continuously withdrawing solidified metal from said receptacle while simultaneously supporting the metal
In said receptacle, cooling and rolling the metal by acting on said solidified metal with reduction rolls located at the lower end of said receptacle.

15. A method of processing molten metal according to claim 1 in which said receptacle is an elongated, upright receptacle having an open-ended passage extending throughout, and the method further comprising continuously withdrawing solidified metal from the bottom of said receptacle while simultaneously supporting the metal in said receptacle and cooling it by acting on said solidified metal with reduction rolls located at the lower end of said receptacle.