METAL REFINING PROCESS

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References Cited
UNITED STATES PATENTS
3,627,293 12/1971 Sperner.......................... 164/52 X

FOREIGN PATENTS OR APPLICATIONS
1,483,646 9/1969 Germany.......................... 164/50

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ABSTRACT

A process for refining metals in which metal introduced to a vessel is refined as it passes in droplet form through a bath of molten slag, comprising introducing the metal in molten state and at a controlled rate to the vessel through one or more apertures which are formed in that part of the vessel wall which confines the slag bath.

12 Claims, 10 Drawing Figures
METAL REFINING PROCESS

The present invention relates to apparatus and processes for the refining of metals. Electroslag refining is an example of such a process. In the electroslag refining process, an electrically conductive slag within a mould is maintained in a molten state and at a temperature above the melting point of the metal to be refined. Unrefined metal is introduced into the mould and is refined as it passes in droplet form through a bath of the molten slag, refined droplets collecting to form a pool beneath the slag bath. The mould wall is cooled by the circulation of a coolant, normally water, and a solidified ingot is built up beneath the molten metal pool.

Previously, metal to be refined has been introduced to the mould in the form of a consumable electrode and the slag maintained molten by passage therethrough of an electric current from the electrode. Alternatively, it has been proposed that the metal be poured into the slag bath from above in powder or molten state through a hollow electrode or from a container. In each of these proposals, the presence of an electrode to maintain the slag at its required temperature has prevented free access to the upper surface of the slag bath.

In accordance with one aspect of the invention, a process for the refining of metals in which metal introduced to a vessel, such as a mould, is refined as it passes in droplet form through a bath of molten slag comprises introducing the metal in molten state and at a controlled rate to the vessel through one or more apertures which are formed in that part of the vessel wall which confines the slag bath.

In accordance with another aspect of the invention, an electroslag refining process in which metal introduced to a mould is refined as it passes in droplet form through a bath of molten slag and collects below the slag bath in a pool which solidifies to form an ingot, comprises introducing the metal to the mould in molten state and at a controlled rate through one or more ports which are formed in that part of the vessel which confines the slag bath.

Molten metal may be conveyed to the aperture(s) through duct(s) the or each of which communicates at its end remote from the vessel with a holding vessel for molten metal. The or each duct may include a water-cooled upwardly inclined section at its end which communicates with the vessel.

A coil having windings connected to a source of alternating current may be mounted about one or more of the ducts to induce a current flow therethrough to heat and/or to cause molten metal within the ducts to flow through the ducts by the pinch effect.

The rate at which molten metal enters the mould may be controlled by controlling the pressures existing above the slag within the vessel and above the molten metal within the holding vessel. Alternatively, the rate of feed of molten metal to the vessel may be controlled by maintaining a metal head within the holding vessel which lies above the lower boundary of the or each aperture formed in the vessel wall. The space within the holding vessel may be evacuated before molten metal is permitted to flow from the holding vessel to degas the metal therein.

The vessel may comprise an open-ended mould having an inverted bell or cone shaped member mounted on or integral with its upper rim, port or ports for the admission of molten metal being formed in the member at such a location or locations that the molten metal enters the molten metal pool at locations away from the mould wall.

In the accompanying diagrammatic drawings,

FIG. 1 is a sectional elevational view of electroslag refining apparatus embodying the invention;

FIG. 2 is a plan view taken from above of the apparatus illustrated in FIG. 1;

FIG. 3 is a sectional elevational view of the apparatus illustrated in FIG. 1 during operation;

FIG. 4 is a plan view from above of further electroslag refining apparatus embodying the invention;

FIGS. 5 and 6 are sectional elevational views of further electroslag refining apparatus embodying the invention;

FIG. 7 is a plan view from above of apparatus in accordance with the invention and including a mould of rectangular cross-section;

FIGS. 8 and 9 are, respectively, plan and sectional elevational views of further electroslag refining apparatus embodying the invention; and

FIG. 10 is a sectional elevational view of modified electroslag refining apparatus in accordance with the invention.

In each of the Figures, like parts bear the same reference numerals.

In FIGS. 1 and 2, apparatus for the electroslag refining of metal includes an open-ended mould 1 mounted on but insulated from a cooled base plate 2. The base plate 2 has a central portion 2a from which protrudes a T shaped key 3. The portion 2a is movable upwards into the mould 1 and downwardly by means of a ram 4. At diametrically opposed positions in the wall of the mould 1 are formed ports 5, 6 which communicate, respectively, with refractory lined ducts 7, 8. The ducts 7, 8 have upwardly inclined water-cooled sections 7a, 8a respectively, preferably of copper, at their ends adjacent the ports 5, 6. Restrictions 7b, 8b are formed in the ducts 7, 8 respectively. The ports 5, 6 are positioned so that, in operation, they will lie within that portion of the mould wall which confines the slag bath. The upper and lower levels of the slag bath are indicated by chain-dotted lines A—A and B—B at their ends remote from the ports 5, 6 the ducts 7, 8 communicate with a holding vessel 9 from molten metal. A coil 10 having windings 11 connected to a source of alternating current is mounted around the duct 7. The windings 11 define a primary circuit and the metal within the ducts 7, 8 and within the vessel 9 defines a secondary circuit. The ducts are of a material, e.g. copper or stainless steel, which does not interfere with the magnetic coupling of the coil and the metal.

The operation of the apparatus will now be described. At start-up, the base plate portion 2a is raised so that its upper surface lies a distance below the lower boundaries of the ports 5, 6 equal to the required slag bath depth. Molten slag is introduced to the mould to a level just below the ports 5, 6. Molten metal to be refined is introduced to the vessel 9 and metal flows through the ducts 7, 8 and into the mould 1 through the ports 5, 6. The metal entering the mould 1 passes through the slag bath and collects as a pool of refined metal on the upper surface of the base plate portion 2a where it freezes around the key 3. Once the slag bath has been displaced by the molten metal to the position indicated by chain-dotted lines A—A and B—B of FIG.
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1, the metal head within the vessel 9 is controlled so that the heads within the upwardly inclined sections 7a, 8a of the ducts 7, 8 lie immediately below the lower boundaries of the ports 5, 6 respectively. The metal within the vessel 9 and the ducts 7, 8 and the slag within the mould 1 are maintained at predetermined temperatures by electrical resistance heating by the passage therethrough of electric current induced by the windings 11 of the coil 10. The resistance of the metal is determined by the length and cross-sectional area of the ducts 7, 8. Additional heating of the molten metal within the vessel 9 may be required and this heat may be supplied by conventional means, e.g. arc heating or induction heating. Molten metal is caused to flow at a controlled rate from the ducts 7, 8 through the ports 5, 6 into the slag bath, by means of the pinch effect. This effect may be controlled by introducing pulses into the current flow to the windings 11 which, in turn, causes the current passing through the metal within the ducts 7, 8 to vary at a frequency and with an intensity proportional to the current flowing through the windings 11. Due to the reduced duct area at each of the restrictions 7b, 8b, the current density in the metal within the restrictions 7b, 8b is at a maximum. Because of smaller inertia of the metal downstream of each restriction compared with that of the metal within the vessel 9, small amounts of molten metal are injected into the mould 1 through the ports 5, 6 by the pinch effect at a frequency proportional to the frequency at which pulses are introduced to the primary windings. The amount of metal introduced is proportional to the intensity of the current.

Alternatively, by suitable positioning of the ducts 7, 8, molten metal may be caused to flow at a controlled rate through the ports 5, 6 by means of the motor effect. For example, at their ends adjacent the vessel 9, the ducts 7, 8 may converge into a V-shaped junction or the ducts 7, 8 may lie adjacent one another along at least a part of their length. As with the arrangement described above, induced electrical pulses within the metal in the ducts 7, 8 cause the metal to be injected into the mould.

The ducts 7, 8 are of such diameter and length that, in operation of the apparatus, sufficient current is induced to flow through the metal contained in the ducts to maintain the metal at a predetermined temperature. Once an ingot of the required height has been formed, the current to the windings 11 of the coil 10 is switched off and the metal within the ducts 7, 8 allowed to freeze. At the start of the next melt, the frozen metal within the ducts 7, 8 may be remelted by the current induced by the windings 11. The current to the windings may be increased initially to facilitate melting of the frozen metal.

The rate of feed of molten metal to the mould 1 may be controlled by constantly feeding molten metal to the vessel 9 to maintain a head which lies above the lower boundaries of the ports 5, 6 or by applying a predetermined pressure in the space above the molten metal in the vessel 9.

As the refining process proceeds, the molten-metal pool formed below the slag bath freezes to form an ingot of refined metal and the base plate portion 2a is lowered by the ram 4 so that the slag bath is maintained substantially in the position indicated by chain dotted lines A—A and B—B.

In FIG. 3, an ingot 12 is shown supported by the base plate portion 2a which has been lowered by the ram 4 to a position below the base plate 2. The slag bath and trough, as indicated at 13 and 14, respectively. In this embodiment, additional heat is introduced to the slag bath 13 by means of an electrical current passed from a cooled copper electrode 15 to the formed ingot. Alternative means of supplying heat to the slag bath may be employed, for example, by one or more plasma torches or by an arc struck from an electrode onto the surface of the slag bath.

In FIG. 4, molten metal is conveyed from the vessel 9 through three refractory lined ducts 7, 8, 16 which communicate, respectively, with three equi-spaced ports 5, 6 17 formed in the wall of the mould. In this embodiment, the coil 10 comprises three windings 11a, 11b 11c, one connected to each phase of a three-phase source of electricity.

It will be appreciated that, depending upon the size and shape of the ingot to be produced, more than three ducts and corresponding ports may be provided.

In FIG. 5, the upper open-end of the mould is closed by a plate 18 and the rate of feed of molten metal to the mould 1 is controlled by balancing the pressures existing within the vessel 9 and within the mould 1. Pipes 19, 20 are provided for admitting an inert gas, e.g. argon or nitrogen, to the spaces above, respectively, the molten liquid in the mould 1 and the vessel 9 to produce the necessary pressure differential to induce a flow of metal from the vessel 9 to the mould 1. Alternatively, a reactive gas, e.g. an oxide of sulphur or carbon, may be employed above the slag within the mould 1. Pressure gauges 21, 22 are provided to record the pressures within the mould 1 and the vessel 9. In this embodiment, the slag bath is heated by means of non-consumable electrodes 23 set in that portion of the mould wall which confines the slag bath.

FIG. 6 illustrates apparatus in which the molten metal within the vessel 9 is degassed prior to being refined in the mould 1. In this embodiment, the vessel 9 communicates via a pipe 25 with a vacuum pump 26. During degassing, communication between the vessel and the pipes 7, 8 is prevented by valves 27 (only one of which is shown) positioned within the exit ports of the vessel 9. Once degassing has been concluded, the valves 27 are opened and the rate of feed of molten metal to the ports 5, 6 is controlled by steadily increasing the pressure existing in the vessel 9.

The apparatus illustrated in FIG. 7 includes a mould 30 of rectangular cross-section for the production of slab-shaped ingots. In this arrangement, the ports 5, 6 are formed in the smaller sides of the mould wall. As in the previous embodiments, more than two such ports may be provided.

In FIGS. 8 and 9, an annular trough 32 extends around the upper periphery of the mould 1 above the liquid metal level within the mould. One or more non-consumable electrodes 33 connected to a source of direct current, extend into the slag bath contained in the trough 32. The return current path from the electrodes may be via the ingot 12 or the base plate portion 2a. Impurities which can be removed from the metal to be refined by electrolysis collect on the electrodes 33 and either leave the trough in gaseous form or collect in the trough, as indicated at 29. The trough 32 may be replaced by one or more pockets into each of which ex-
tends an electrode connected to a source of direct current. In FIG. 10, the mould 1 includes a detachable member 40 of inverted bell- or cone-shape which is mounted on the upper rim of the mould 1. The member 40 (which is water-cooled and may be of copper) comprises an upper portion 41 of reduced cross-section in which are formed ports 42, 43; in the same way as the ports 5, 6 of FIG. 1 communicate via the ducts 7, 8 with the vessel 9, so the ports 42, 43 communicate via ducting 7, 8 with a molten metal holding vessel. The portion 41 ensures that molten metal which enters through the ports 42, 43 enters the metal pool at a location away from the mould wall and the reduced area of the upper surface of the slag bath reduces heat losses. The upper open-end of the member 40 may be covered.

In an alternative arrangement, the member 40 is integral with the mould 1.

Advantages of a refining process in which free access to the upper surface of the slag bath is possible are:

1. temperature measurements of the slag bath and molten metal pool can be readily made and slag and metal samples taken;
2. metallic constituents such as manganese, chromium, nickel or aluminium which are required to adjust the chemical composition of the metal or to prevent undesirable reactions, may be added to the slag bath during the refining process;
3. additional heating of the slag, for example, by means of non-consumable electrodes, can be effected as and when required; and
4. mandrels supported from above can be suspended into the mould for the manufacture of tubular ingots or for the cladding of rolls.

Further advantages of the present invention are that contamination of the molten metal by the atmosphere is prevented since the metal enters the slag bath below the surface thereof. Also, compared with conventional electroslag refining apparatus, the apparatus is considerably simplified because there is no need to provide heavy and complicated electrode lifting gear and there is no need to form the metal which is to be refined into an electrode before refining can be carried out.

The process is particularly suitable for use in the refining of steel.

We claim:

1. In a process for producing an ingot of refined metal which comprises introducing unrefined metal to a bath of molten refining slag present in a vessel having an upstanding side wall, causing the unrefined metal to pass through the slag bath in droplet form and to collect in a pool of refined metal below the slag bath, and causing the pool of refined metal to freeze progressively to form an ingot, the improvement which comprises introducing the unrefined metal to the vessel in molten state and at a controlled rate through a passage which is formed in the side wall of the vessel and terminates in an aperture which is positioned below the surface of the slag bath and above the surface of the metal pool, whereby droplets of unrefined metal are refined by contact with molten slag as they are formed in said passage and as they pass through the slag bath from the aperture to the pool of refined metal.

2. A process according to claim 1 wherein the vessel is a mould and wherein molten metal is conveyed to the aperture through ducting which places the mould in communication with a holding vessel for molten metal.

3. A process according to claim 2 wherein a plurality of apertures are formed in the mould wall, each aperture being placed in communication with the holding vessel by means of a duct having an upwardly inclined section at its end adjacent the aperture.

4. A process according to claim 3 wherein the upwardly inclined duct section is water-cooled.

5. A process according to claim 3 wherein the mould is circular in cross-section and wherein the apertures are equally spaced about the circumference of the mould.

6. A process according to claim 5 wherein the mould is rectangular in cross-section and wherein the apertures are formed in the smaller sides of the mould.

7. A process according to claim 3 wherein a coil having a winding connected to a source of alternating current is mounted about at least one of the ducts to induce a flow of electrical current through molten metal contained in the ducts and the holding vessel and through the slag bath.

8. A process according to claim 7 wherein coils are mounted about a plurality of ducts, the windings of the coils being connected one to each phase of a polyphase alternating current.

9. A process according to claim 7 wherein a flow restriction is formed in each duct and wherein molten metal is introduced to the mould by the pinch effect at a rate determined by the intensity of the current conveyed to the winding of the or each coil.

10. A process according to claim 2 wherein the rate at which molten metal is introduced to the mould is controlled by controlling the gaseous pressures existing above the slag within the mould and above the metal within the holding vessel.

11. A process according to claim 2 wherein the rate at which molten metal is introduced to the mould is controlled by controlling the head of the metal within the holding vessel in relation to the level of the lower boundary of the aperture formed in the mould wall.

12. A process according to claim 2 wherein the space within the holding vessel is evacuated before molten metal is permitted to flow from the holding vessel to degas the metal contained therein.