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Luchok et al.

[11] **3,834,447**

[45] **Sept. 10, 1974**

[54] **APPARATUS FOR CASTING A PLURALITY OF INGOTS IN A CONSUMABLE ELECTRODE FURNACE**

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[21] Appl. No.: **358,742**

Related U.S. Application Data

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[52] **U.S. Cl.** ..... **164/273 M**, 164/281

[51] **Int. Cl.** **B22d 11/10**

[58] **Field of Search** ..... 164/52, 123, 252, 281, 164/337, 273 M

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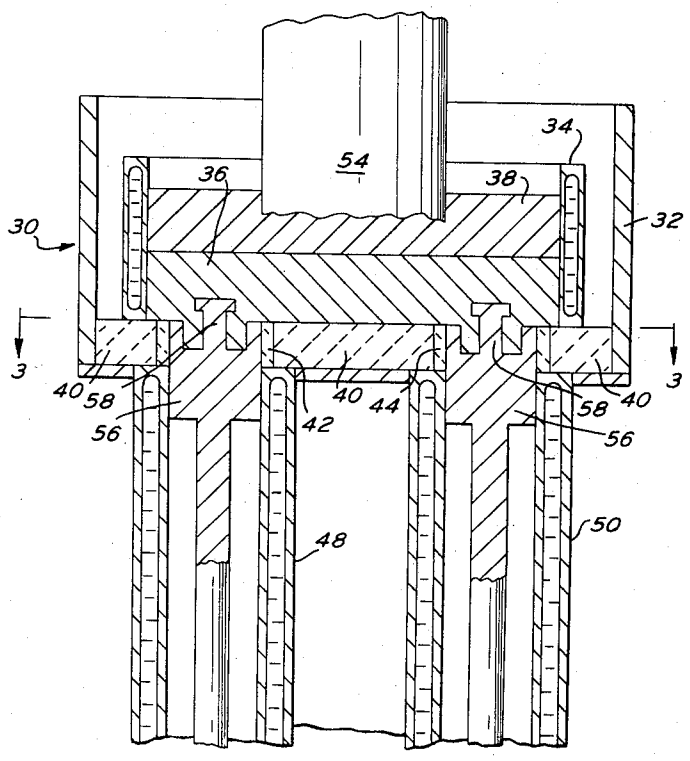
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Attorney, Agent, or Firm—Seidel, Gonda & Goldhammer

[57] **ABSTRACT**

A method and apparatus for continuously casting one or more ingots by maintaining a pool of molten metal in a first ingot section that has a larger transverse cross sectional area than the transverse cross sectional area of the ingot mold or molds which are in open communication with said first ingot section by causing said molten metal to flow continuously from said pool into said ingot mold or molds while preventing the molten metal in said pool from freezing at the interface of said first mold section and said mold or molds. A refractory lining for said first mold section is used to prevent the molten metal from freezing.

3 Claims, 5 Drawing Figures



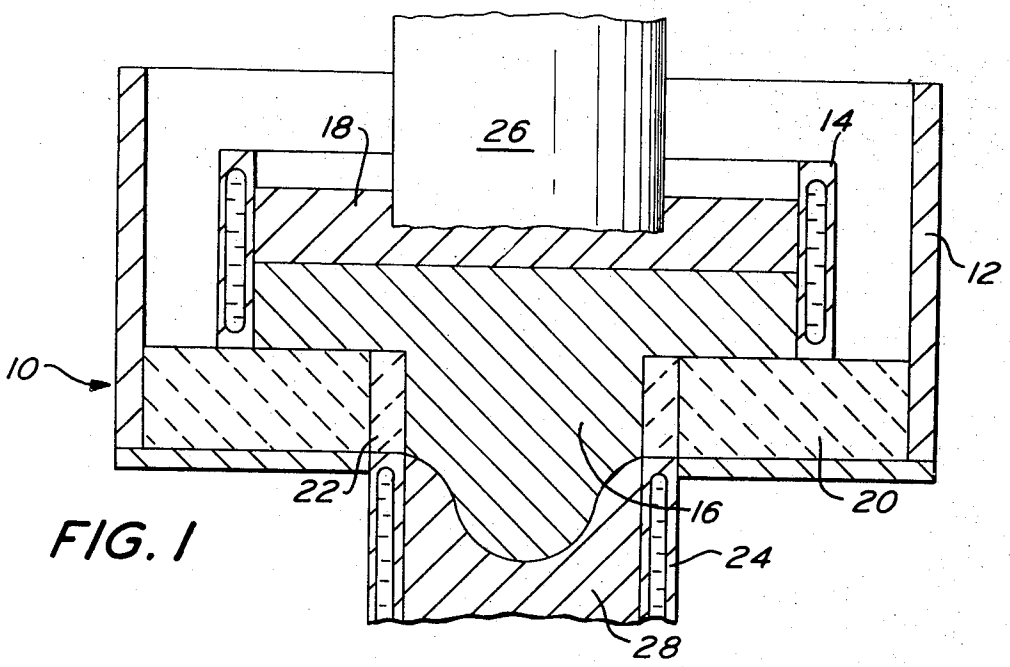


FIG. 1

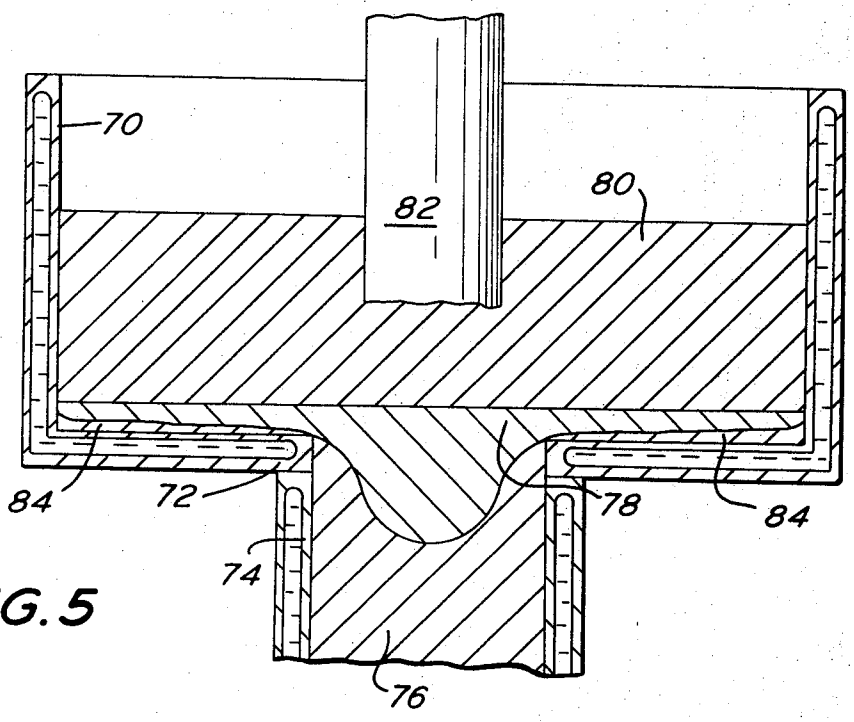


FIG. 5

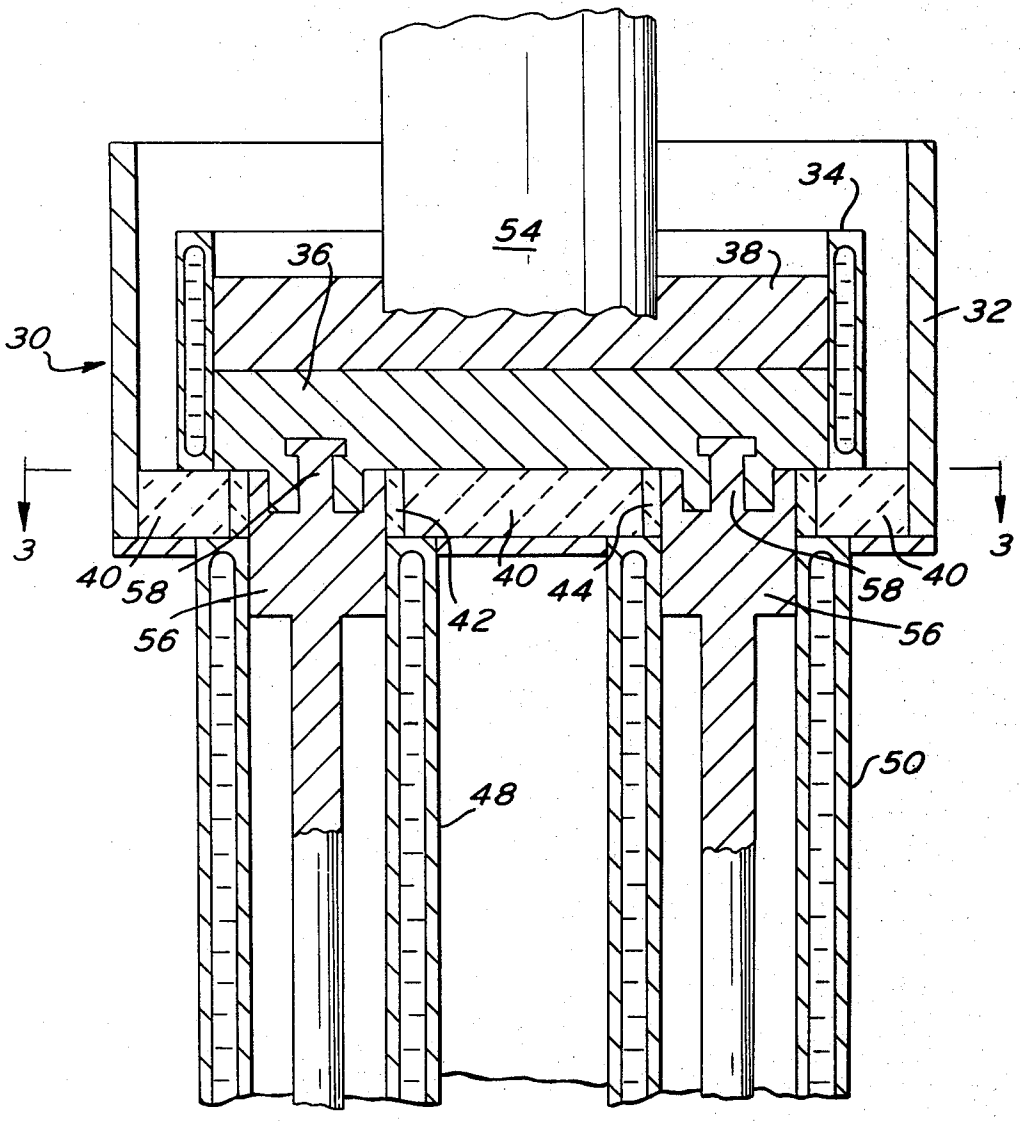
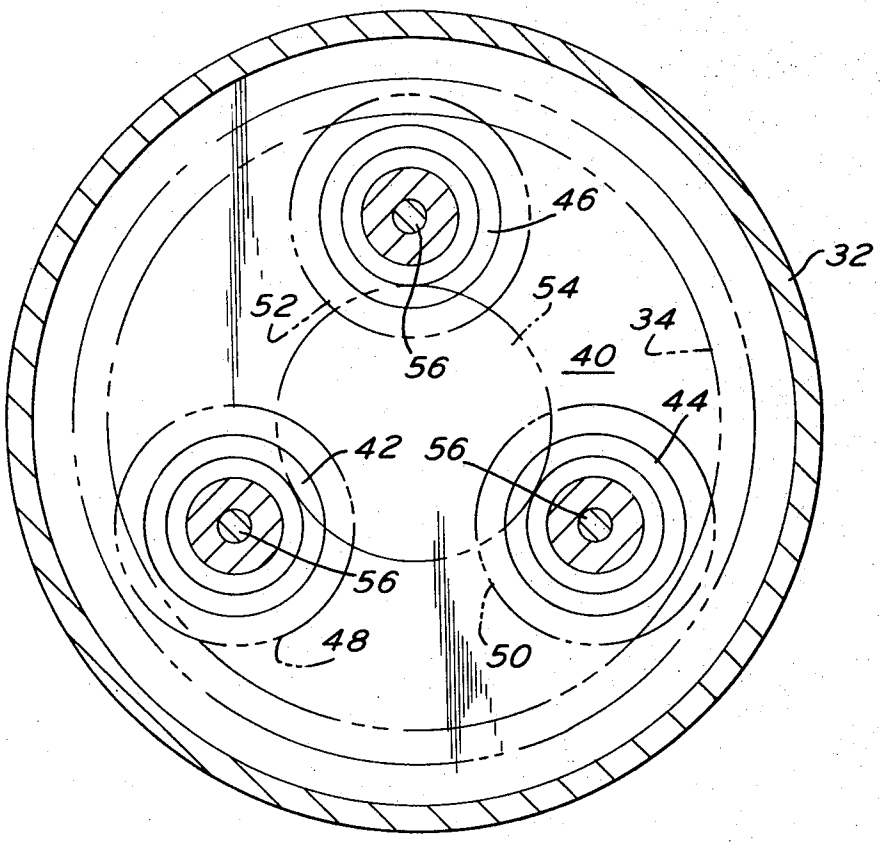


FIG. 2

FIG. 3



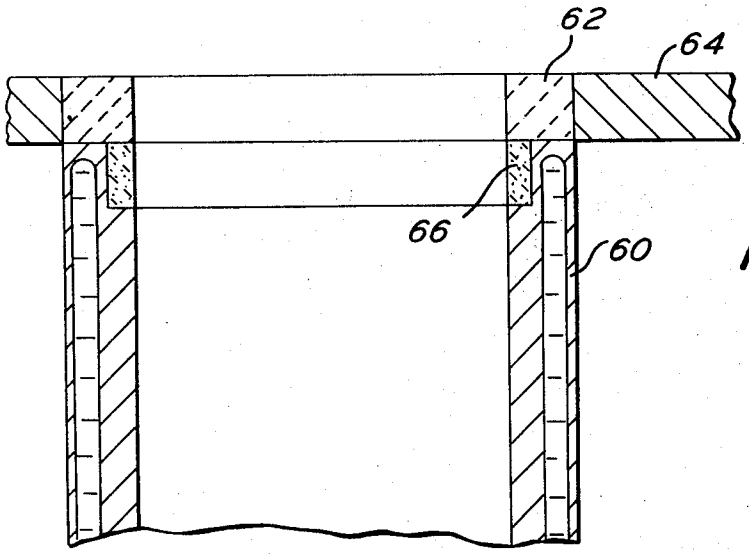


FIG. 4

APPARATUS FOR CASTING A PLURALITY OF INGOTS IN A CONSUMABLE ELECTRODE FURNACE

This is a division of application Ser. No. 177,939 filed Sept. 7, 1971 now U.S. Pat. No. 3,782,445.

This invention relates to a method and apparatus for casting ingots. More particularly, this invention relates to a method and apparatus for simultaneously melting single large electrodes or multiple electrodes and casting multiple ingots. Still more particularly, the present invention relates to a method and apparatus for simultaneously and continuously casting a plurality of ingots from a single large electrode or multiple electrodes melted according to the electroslag process into a common slag bath.

The manufacture of ingots according to any one of several consumable electrode processes generally contemplates the melting or remelting of an electrode into an ingot whose cross sectional area is larger than that of the electrode. In common practice, the ratio of electrode to ingot cross sectional area ranges up to about 80 percent. In certain instances it is desirable for the ratio of the electrode to the ingot cross sectional area to equal or exceed **100%**; that is, it is often desirable to manufacture an ingot whose cross sectional area is smaller than the cross sectional area of the electrode. Unfortunately, there are certain metallurgical and economic restrictions which make the foregoing desirable result difficult to achieve. The present invention provides a method and apparatus that allows the electrode to ingot cross sectional ratio to equal or exceed 100 percent. More particularly, the present invention allows the simultaneous casting of two or more ingots.

The cost of ingot manufacture in the electroslag remelting or other consumable electrode processes is in part a function of a melt rate which in turn is a function of the ingot cross sectional area. Thus, the smaller the ingot cross sectional area, the fewer pounds per minute can be cast. Stated otherwise, the tolerable solidification rate for a given alloy is a function of the metallurgical characteristics and quality standards established by specification. As a general rule, the tolerable solidification rate decreases with the decrease in ingot cross sectional area. Therefore, it can be stated that low melt rates result in poor furnace utilization and thus drive up the unit cost of producing ingots by conventional electroslag remelting or other consumable electrode processes.

Also, the cost of manufacturing an electrode to be used in the consumable process increases as the diameter of the electrode decreases. Consequently, the manufacture of small ingots by consumable electrode processes, and in particular the electroslag remelting process, has heretofore not been widely adopted for use in the manufacture of ingots of small cross sectional area.

The present invention relates to a method and apparatus for overcoming the inherent difficulties in manufacturing ingots with a cross sectional ratio equal to or in excess of 100 percent and, in particular, to a method and apparatus for the continuous simultaneous casting two or more ingots from a pool of liquid metal.

In the specific process described herein, a molten metal pool is formed as the result of melting (fusing) an electrode by the classic electroslag remelting process. This process involves suspending an electrical conductor in the form of an electrode so that its lower end is immersed in a liquid slag bath. The lower end of the electrode is melted by passing current through the electrode and slag in a manner such that molten metal droplets drop from the electrode through the slag layer and thus form a molten metal bath. An ingot or ingots are withdrawn from this bath.

Although described in terms of the electroslag remelting process, it should be understood that the invention can be applied to other electrode remelting processes such as a vacuum arc or a nonconsumable process.

In particular, the invented process and apparatus for performing the process contemplates the continuous casting of one or more ingots from a pool of liquid metal. This is in contrast to the more typical process of manufacturing an ingot which merely maintains a pool of molten metal at the head of the individual ingot being formed. By having a common pool, it is possible to cast several ingots simultaneously. Still further, the present invention makes it possible to manufacture ingots having a relatively small cross sectional area using the electroslag process. Generally speaking, an ingot is considered to have a small cross sectional area if it has a diameter of eight inches or less. However, it should be understood that the present invention is not limited to the manufacture of small ingots. Moreover, the cross sectional form of the ingots may be any practical configuration such as round, square, rectangular, or even tubular.

In accordance with the present invention, the furnace is constructed so as to provide a first mold section whose cross sectional area is larger than that of the ingot mold or molds which open into the first mold section. To cast an ingot or ingots, the pool of molten metal is first formed in the mold section of larger cross sectional area and thereafter such pool of molten metal is caused to flow into the ingot mold. It is a significant attribute of the present invention that the pool of molten metal in the first mold section is maintained in a molten metal condition. In other words, no skull which would prevent ingot removal is permitted to form in the first mold section.

As previously stated, a significant feature of the present invention is that it allows the simultaneous casting of more than one ingot, thus significantly increasing the productive capacity of an electroslag remelting furnace. By way of example, a given alloy may for metallurgical reasons be capable of only being cast as a 6 inch diameter ingot at a maximum rate of 200 pounds per hour. By designing a furnace so that four ingots are withdrawn simultaneously, it is now possible to use a large diameter electrode. Electrode manufacturing costs are thereby reduced while the total furnace output of (4×200) or 800 pounds per hour greatly improves the furnace productivity and thus reduces unit manufacturing costs.

There is disclosed in patent application Ser. No. 761,893 filed Sept. 16, 1968, now U.S. Pat. No. 3,602,623, a process for simultaneously manufacturing a plurality of ingots. The invention disclosed therein is a significant contribution to the consumable electrode method of manufacturing ingots, particularly in connection with electroslag remelting. However, it is patentably different from the present invention in that it contemplates the simultaneous melting of a plurality of ingots into a plurality of crucibles using a common

power supply and a common regulator control. There is no common pool of molten metal. The present invention contemplates the manufacture of one or more ingots by causing molten metal to flow into the ingot mold or mold from a common pool.

Rheinstahl French patent publication 2,023,908 discloses a process for the production of an ingot from an electrode whose cross sectional area is larger than that of the ingot. The furnace has a conical upper portion that is in open communication with a generally cylindrical or slightly tapered crucibles for forming the ingot. The Rheinstahl publication contemplates the manufacture of an ingot whose cross sectional area is smaller than that of the electrode.

In the Rheinstahl publication, the pool of molten metal is conventionally maintained in the ingot mold portion of the furnace. In accordance with the present invention, the pool of molten metal is maintained in what would correspond to the upper or funnel portion of the furnace. Any attempt to operate the furnace described in the Rheinstahl publication with the molten metal pool in the upper portion would result in solidification of the molten metal adjacent the crucible walls. This would make it impossible to withdraw the ingot or, at the very least, would result in unacceptable tearing.

As previously explained, it is one of the major purposes of the present invention to provide a simple, flexible, low cost means of producing one or more ingots from a common pool of molten metal. It is too complex to add ingot molds to a furnace, but maintain individual pools of molten metal in each ingot mold. There are difficult problems in maintaining uniform ingot buildup, monitoring and controlling the location of the slag-metal interface in each ingot position, and the necessity for multiple ingot withdrawal mechanisms. Moreover, the furnace system must be capable of being operated by a unsophisticated workman. Of course, any attempt to simply move the molten metal pool up into the upper, funnel like mold section as in Rheinstahl must fail because of the formation of a skull.

In accordance with the present invention a method and apparatus for maintaining a pool of molten metal in a first mold section of larger diameter than the ingot mold or molds is provided. It has been found that a thermal insulator such as a refractory lining provided in the first mold section prevents the formation of a skull and thus permits the maintenance of the molten pool in the first mold section. Stated otherwise, the provision of a refractory lining in the first mold section allows the molten metal-slag interface to also be maintained in the first mold section. Accordingly, the first mold section can be of a larger diameter than the ingot mold and be in communication with more than one section ingot mold.

For the purpose of illustrating the invention, there are shown in the drawings forms which are presently preferred; it being understood, however, that this invention is not limited to the precise arrangements and instrumentalities shown.

FIG. **1** is a transverse sectional view of an electroslag furnace constructed in accordance with the principles of the present invention for performing the processes described herein.

FIG. **2** is an electroslag furnace constructed in accordance with the present invention for performing the processes described herein.

FIG. **3** is a plan view of the furnace illustrated in FIG. **2.**

FIG. **4** is a partial sectional view illustrating another embodiment of the present invention.

FIG. **5** is a sectional view illustrating yet another embodiment of the present invention.

Referring now to the drawing in detail, there is shown in FIG. **1** a sectional view of a furnace **10,** which when constructed in accordance with the principles of the present invention, provides a method and apparatus for casting ingots.

The furnace **10** includes an outer support shell **12** which houses an upper water cooled copper jacket **14** used to contain the molten metal **16** and the molten slag **18.** The support shell **12** is provided with a refractory bottom **20.** The refractory bottom **20** includes a replaceable refractory upper mold insert sleeve **22** which may be annular in construction. The water cooled jacket **14** together with the refractory bottom **20** and its insert **22** define what may hereinafter be referred to as a first mold section.

In direct, open communication with the first mold section through the refractory sleeve **22** is the water cooled copper ingot mold **24.** It is in the copper ingot mold **24** that ingots are continuously formed and withdrawn as solidification proceeds.

An electrode **26** is reciprocably supported with its end in the molten slag **18** by conventional apparatus for that purpose, not shown. It should be noted that the electrode **26** has a cross sectional area substantially larger than the cross sectional area of the ingot mold **24** and hence the ingot **28** being formed therein. However, it should be understood that in certain circumstances it may be advantageous to use several electrodes **26** of any convenient cross sectional area simultaneously being fused under the slag **18** to form the molten metal pool **16.**

The first mold section has a larger cross sectional area than that of the ingot mold. It is in this expanded mold section that the molten slag-molten metal interface is maintained. Stated otherwise, the pool of molten metal is allowed to be formed in said first mold section.

The refractory bottom **20** together with the refractory insert sleeve **22** provide thermal insulation allowing the molten metal pool **16** to remain molten. Should any portion of the pool **16** that extends above the refractory bottom **20** become solidified, than the ingot **28** would either become jammed in the ingot mold **24,** or tearing on the surface of the ingot would occur, or removal would be impossible. Thus, the refractory bottom **20** and refractory sleeve **22** sufficiently insulate molten metal from the cooling effects of the ingot mold **24** and the jacket **14** to prevent solidification at or near the interface between the ingot mold **24** and the first mold section. By preventing the solidification of the molten metal **16** in the first mold section, it is now possible to maintain a pool of molten metal as well as the metal-slag interface in said first mold section.

By way of example, but not limitation, the refractory bottom **20** and refractory sleeve **22** could be made of Zirconia (ZrO_2). Zirconia is advantageous because it can remain in contact with molten steel for long periods of time with minimum reaction tendencies. Moreover, it can also survive with minimum erosion (or solutioning) during the molten slag start and molten metal buildup period. It should be understood that the refrac-

tory bottom **20** and refractory sleeve **22** are not limited to being made of Zirconia. Other refractory products which perform the same function may be substituted. Indeed, even non-refractory materials which insulate the molten metal sufficiently to keep it in a molten condition can be substituted.

The purpose in using a replaceable sleeve **22** at the head of the ingot mold **24** is so that it can be replaced since this is the area of maximum wear.

In operation, the furnace is started in accordance with the process described below in respect to FIG. **2** or by using a water cooled copper starting plug such as is known in the industry. The electrode **26** is positioned about three to four inches from the starter plug and energized. Molten slag is poured into the first mold section until its level rises to the electrode tip. Thereafter, the melting process begins. If desired, the refractory bottom **20** and refractory sleeve **22** can be preheated such as by use of a torch prior to the addition of the molten slag.

During the first few minutes, the electrode melts at a predetermined rate, thereby covering the first mold section refractory bottom **20** and starter plugs with molten metal. After the pool of molten metal is formed, ingot withdrawal is initiated and subsequently maintained at a rate equivalent to the melt off rate of the electrode. Ingot withdrawal can be accomplished by any conventional means such as by lowering the ingot from a fixed mold **24** or by raising the mold from a fixed ingot. Both processes and apparatus for accomplishing the same are known and therefore need not be described in detail.

Of course, the ingot formation rate is varied depending upon ingot size (cross sectional area) and the structure required of a given alloy. At the conclusion of the melt, electrical power is reduced or turned off while ingot extraction is allowed to proceed thus emptying the upper chamber of molten steel. The molten slag can be removed by the same process, or it can be removed by another method such as by siphoning.

The apparatus described with respect to FIG. **1** illustrates how an ingot **28** can be made with a smaller cross sectional area than the cross sectional area of an electrode **26.**

It should be noted that metal solidification takes place entirely within the ingot mold **24.** Tests have shown initial solidification of the metal takes place at the point of abutment between the refractory sleeve **22** and the water cooled ingot mold **24.**

Referring now to FIGS. **2** and **3,** there is shown a furnace **30** for simultaneously making several ingots using essentially the same method described in respect to the operation of the furnace **10.** As shown in FIGS. **2** and **3,** the furnace **30** comprises an outer shell **32** for housing an upper water cooled copper jacket **34** which is used to contain the molten metal **36** and molten slag **38.** The furnace **30** is provided with a refractory bottom **40** having, by way of example, three openings which provide communication with the water cooled, copper ingot molds **48, 50** and **52.** Refractory sleeves **42, 44** and **46** are provided at the head of each ingot mold. As previously stated, such sleeves are adapted to be replaced when worn and are of annular construction. The refractory bottom **40** and refractory sleeves **42, 44** and **46** are preferably made of Zirconia, although other suitable materials may be used for providing the requisite heat insulation.

Although three ingot molds of cylindrical construction are illustrated in FIGS. **2** and **3,** it should be understood that this is by way of example. The furnace could equally well be constructed with two, four or more molds. Moreover, the cross sectional shape of the molds could be other than cylindrical, if desired.

A single electrode is shown in operating position with its tip inserted into the molten slag **38.** The electrode **54** may be reciprocably supported by any conventional electrode support apparatus.

For starting the process using the furnace illustrated in FIGS. **2** and **3,** starting plugs **56** are inserted into each of the ingot molds **48, 50** and **52** so that their top portion is approximately level with the top of the refractory sleeves **42, 44** and **46.** One of the purposes of positioning the plugs **56** as such is to protect the refractory sleeves from attack by molten slag during start up. As shown, each of the plugs is provided with a table like portion standing on a pedestal within a recess designated generally as **58.** This is to provide the good connection with each of the ingots to be formed by withdrawal of molten metal from the common pool **36.**

After start up in accordance with the procedure described in respect to the furnace **10,** ingots are formed in each of the molds by ingot withdrawal at a rate determined by the melt rate of the electrode and the alloy requirements. Thus, a plurality of ingots can be simultaneously formed from a common pool of molten metal.

Control of the rate of formation of the ingots depends substantially in part upon the position of the molten metal-slag interface. Since there is only one such interface, control problems are substantially reduced as compared with trying to maintain a molten metal slag interface in each of the ingot molds **48, 50** and **52.** Since there is only one molten metal-slag interface conventional controls can be used.

Referring now to FIG. **4,** there is shown a partial cross section of the junction between a water cooled ingot mold **60** and the bottom of a first mold section for containing the metal reservoir. A refractory sleeve **62** and refractory bottom **64** are provided as in the embodiment illustrated in FIGS. **1** and **2.** In addition, a graphite sleeve **66** is fitted into the wall of the ingot mold **60** in abutment with the refractory sleeve **62.**

The purpose of using the graphite sleeve **66** is to take advantage of its low friction qualities. Such a sleeve would improve the surface quality of the ingot being formed in the mold **60.** The sleeve **66,** however must be cooled since carbon will dissolve into steel if it is allowed to get too hot. For this reason, the sleeve **66** is relatively thin and is positioned in a channel formed in the wall of ingot mold **60** so that it is cooled.

In the event the alloy being cast can tolerate direct exposure to carbon, such as a copper alloy, then the refractory sleeve **62** or even the refractory bottom **64** could be made of graphite.

FIG. **5** illustrates apparatus for yet another embodiment of the inventive concept. In this embodiment the entire first mold section consists of a water cooled structure **70.** Stated otherwise, the bottom **72** of the upper mold section is also water cooled even in the area adjacent to the ingot mold **74.**

In operating a furnace to produce a continuously cast ingot **76** by withdrawing it from the pool of molten metal **78** which is maintained in the first mold section by fusing the electrode **82** in the slag bath **80,** the mol-

ten metal is prevented from solidifying by taking advantage of the thermal insulating properties of slag. Thus, at start up, a thin layer of slag **84** is initially formed in the bottom of the first mold section and allowed to freeze. Thereafter, the formation of the ingot **76** proceeds as previously described. The result is that the thin layer of slag **84** acts as a thermal insulator for preventing the molten metal for solidifying in the expanded first section.

Although each of the embodiments illustrated and described herein have contemplated vertical extraction of the ingot or ingots, the invention is not restricted to that configuration. The processes described herein could equally well be used for horizontal extraction of an ingot or ingots.

Although the first mold section and the ingot mold or molds are preferably made of water cooled copper, it should be understood that water cooled steel or other known types of molds that are compatible with the process could be used. Still further, the process is not limited to the use of consumable electrodes. It is contemplated that nonconsumable electrodes or other methods of melting molten metal in the first mold section could be used with equal facility.

Furnaces operated in accordance with the processes described herein may be used either for continuous casting or for the manufacture of individual ingots. Electroslag remelting would be somewhat slower than known processes for continuous casting, but the result is a better product. Better quality alloys result when they are permitted to solidify at a slower rate. Such slower solidification rates occur because the slag blanket on top of the molten metal helps maintain heat in the pool of molten metal. Moreover, the slag blanket prevents freezing from the edge of the pool of molten metal at the slag-metal interface.

As previously indicated, one of the major advantages of the apparatus and method described herein is that multiple ingots can be made from a common pool of molten metal. The process permits the use of electrodes melting at a relatively high rate while the ingots are being cast at a relatively slower rate. Stated otherwise, this means that the rate of casting an ingot is not strictly controlled by the rate at which the molten metal pool is being formed.

The present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof and, accordingly, reference should be made to the appended claims, rather than to the foregoing specification as indicating the scope of the invention.

We claim:

1. Apparatus for simultaneously casting a plurality of metal ingots in a consumable electrode electroslag furnace in which an electrode is fused under slag to form molten metal to be cast into ingots, comprising:

a first mold section for containing molten metal and slag,

a plurality of ingot molds in direct communication with said first mold section,

said first mold section having a larger cross-sectional area than the total cross-sectional area of the ingot molds in communication therewith,

cooling means operatively associated with each of said plurality of ingot molds for cooling said ingot molds and solidifying ingots therein,

said first mold section being adapted to retain therein a pool of molten metal in intimate contact with each of the ingot molds throughout the full cross-section thereof and including for that purpose heat insulating means to prevent the pool of molten metal from solidifying in said first mold section at the interface between said first mold section and said ingot molds,

said first mold section also being adapted to retain therein a pool of molten slag overlying said pool of molten metal,

said heat insulating means being securely mounted on the top of said ingot molds and on the bottom of said first mold section and disposed entirely beneath the top level of said pool of molten metal,

said first mold section also including a liquid cooled metal jacket extending above the heat insulating means, said jacket being adapted to contain the molten metal and molten slag overlying said molten metal.

2. Apparatus in accordance with claim **1** wherein said means for preventing solidification of molten metal in the first mold section is a refractory material.

3. Apparatus in accordance with claim **2** wherein said refractory material is zirconia.

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