

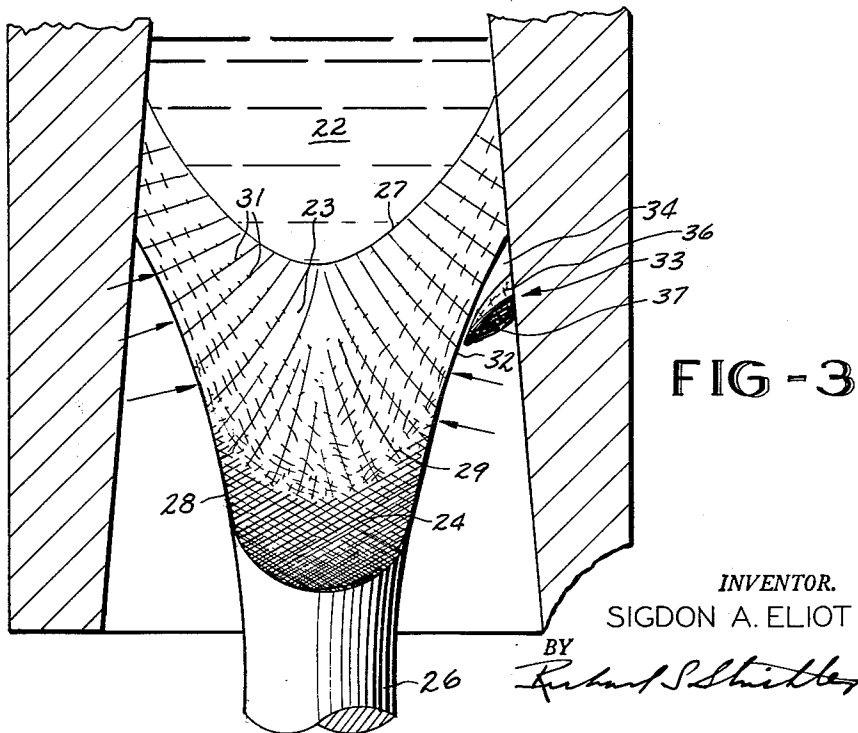
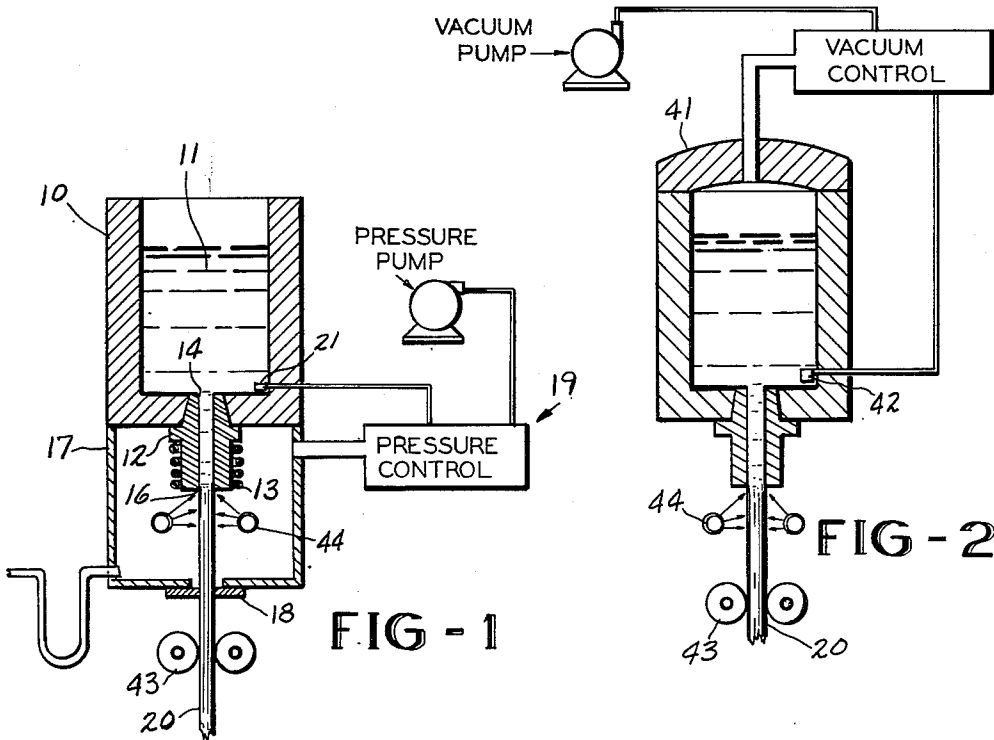
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APPARATUS AND PROCESS FOR CONTINUOUS CASTING

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The present invention relates to continuous casting machines and to methods of casting continuously.

In particular, the invention relates to continuous casting machines which are charged with metals alloyed with constituents which have different melting points; such alloys are sometimes referred to as embracing high melting phases and low melting phases.

Brasses containing various compositions of copper and zinc represent examples of metals whose continuous casting characteristics are especially enhanced by the practice of the principles of the present invention.

It is a particular feature of the present invention to provide a novel casting process.

It is a further feature of the invention to provide a novel casting apparatus.

It is a further object of the invention to provide a vertical casting apparatus in which there is a minimum of friction in the forming die.

Another object of the invention is the provision of a casting apparatus where cooling of the forming die is optional.

A further object of the invention is the provision of a continuous vertical casting apparatus which is not plagued with die failure such as by cracking, splitting, gouging or spalling.

It is a still further feature of the invention to provide a scheme for continuously casting metal from a molten metal crucible through a forming die disposed below the crucible where the pressure upon the metal in the forming die arising from the head of metal in the crucible is counterbalanced.

A further feature of the invention is the provision of a continuous casting machine wherein the pressure differential measured across the solidification front in the region of the forming die is substantially eliminated.

A still further object of the present invention is the provision of a continuous casting process which is particularly useful when treating alloys having at least two constituents having different melting points.

A further feature of the invention is the provision of a continuous casting process adapted to process metals composed of constituents having a plurality of melting phases wherein the effect of sequential freezing of the several melting phases is controlled to preclude the low melting phase from bleeding or exuding through the high melting phase.

A casting apparatus embracing certain features of the invention may comprise a forming die, a reservoir for containing molten metal disposed above the die and communicating therewith, the temperature of the die and the casting rate being so controlled that a solidification front is maintained within the die or immediately adjacent the die opening, quenching means for chilling the metal after it leaves the die, means for withdrawing solidified metal from the die, and pressure control means responsive to the head of metal in the reservoir for controlling the pressure differential across the solidification front to the extent that the differential results from the head of molten metal.

A casting process embracing the principles of the present invention may include the steps of continuously supplying molten metal from a reservoir to a forming die disposed below the reservoir, continuously withdrawing

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solidified metal from the forming die, maintaining a solidification front within the die or immediately adjacent the die opening, and eliminating a pressure differential occurring across the solidification front to the extent that the differential is generated by the head or hydrostatic pressure of molten metal.

Other features and advantages of the present invention will become more apparent from the succeeding specification when read in conjunction with the appended drawings, in which:

FIG. 1 illustrates, schematically, an apparatus which may be utilized to practice the principles of the present invention;

FIG. 2 shows an alternative embodiment of the invention while;

FIG. 3 is an enlarged view of a forming die showing the solidification front and a typical dendritic structure which develops upon freezing of a multiple melting phase non-ferrous alloy such as a copper base alloy.

Referring now in detail to the drawings, there is shown in FIG. 1 a crucible 10, filled with a molten non-ferrous alloy 11, communicating with a graphite forming die 12 suitably jacketed by heat transfer coils 13. The coils 13 are available for hot or cold heat transfer fluids as the particular alloy being cast and the casting speed may require. The die, disposed vertically, is formed with an inlet 14 and an outlet 16 and may be tapered so that the walls diverge or flare as is apparent in the enlarged view of the die illustrated in FIG. 3.

The discharge side of the forming die is enclosed in a substantially fluid-tight chamber 17 fitted with a suitable gland or seal 18 surrounding a continuously advancing cast cross section 20. The chamber 17 is filled with an appropriate gas effective to develop a reducing or a chemically inert atmosphere, as desired. The character of the gas is not critical and it is anticipated that gas selected will vary with the characteristics of the particular alloy being cast.

A pressure control device including a conventional pressure regulating valve and a pressure pump, shown schematically at 19, communicates with the interior of the chamber 17 and is operative to supply the selected gas atmosphere and to maintain the pressure thereof at a predetermined value. The value of the pressure within the chamber 17 is determined by the value of the pressure developed by the hydrostatic head of molten metal in the crucible 10. Consequently, an appropriate pressure sensing unit, indicated generally by the reference numeral 21, is disposed in the interior of the molten metal 11, at the bottom of the crucible 10 and continuously "reads" the pressure developed by the head of the metal.

The pressure sensing unit 21 communicates with the pressure control device 19 and is operative to transmit a signal corresponding to the pressure which the sensing unit continuously reads. The control unit 19, in turn, responds to the signal by supplying gas to the chamber 17 at a pressure corresponding to the signal transmitted by the sensing unit 21.

In this fashion a pressure is generated within the chamber 17 which effectively counterbalances the pressure developed by the head of molten metal within the crucible 10.

Obviously, the control device 19 may be set to produce a pressure in the chamber 17 which is exactly equivalent to the pressure developed by the head of molten metal in the crucible 11, or the control unit may be adjusted to produce a value of pressure within the chamber which is a constant amount more or less than the hydrostatic head pressure of the molten metal, as desired. For example, an increment of pressure may be applied to correct for a relatively constant head in the die itself as against

the moving head in the crucible as the level therein drops.

A convenient way to describe the effect of the pressure developed in the chamber 17 is to state that, in effect, the metal within the die, especially in the region thereof where the transition from liquid to solid is occurring, is buoyed up or supported in a direction normal to the external surface of the metal as shown by the arrows of FIG. 3. As will be pointed out hereinafter, it is very desirable to provide support to the cross section being cast in this transition area frequently referred to as the solidification front.

In order to reduce the head which must be counterbalanced to a minimum it is possible to separate the die from the reservoir. In this arrangement, the molten metal flows through a gap in passing from the reservoir into the die and the differential pressure is maintained across the inlet and discharge sides of the die.

Referring now in detail to FIG. 3, there is shown, schematically, a typical die cross section illustrating the solidification front of a wide solidification zone alloy such as a copper base alloy.

Attention is particularly directed to the molten alloy 22, the initial dendritic growth of the high melting constituent of the alloy occurring in the area labelled 23, the subsequent virtually solid region indicated by the reference numeral 24 and the solid condition 26.

The solidification front is defined by the region between the curve labelled 27 and the curve labelled 28. Obviously, the speed of casting can be increased until the solidification front is displaced from within the die to a position beyond the discharge side of the die.

As stated previously, the forming die may flare and diverge toward the outlet side while the solid casting shrinks upon freezing so that there is a substantial gap at the discharge side of the die which extends upwardly toward the central region thereof as shown in FIG. 3.

At this point it is well to point out the function, operation and advantages that are achieved by the apparatus and process steps of the present invention paying particular attention to the desirable results obtained by buoying up the cast cross section in the region of the solidification front.

Obviously, molten metal 22 develops a head of pressure which bears downwardly upon the front.

In the upper regions of the front, specifically in the areas bounded by the curves 27 and 29, the high melting phase of the material being cast has begun to crystallize or freeze out developing channeled dendritic growth as indicated by the special hatching labelled 31 while the low melting phase remains fluid between the dendritic structure. Obviously the low melting phase in the fluid condition is under the influence of the head pressure developed by the molten metal 11 of FIG. 1 (labelled 22 in FIG. 3).

The result is that, in the absence of a pressure to counterbalance the head generated by the molten alloy above the solidification front, the low melting phase, in liquid form, bleeds, exudes, or is otherwise forced or squeezed out through the skin 32 of the cast cross section to form a wedge of molten material, indicated generally by the reference numeral 33.

The wedge occurs around the full periphery of the cross section being cast and is shown here only on the right side in FIG. 3 for convenience.

Obviously, bleeding first occurs in the form of liquid 34 which subsequently converts into a semi-solid condition 36 and finally exists as a solid as at 37 due to the natural thermal gradient within the die. The occurrence of bleeding and the subsequent freezing of a wedge of solid material creates increased frictional drag through the die and is frequently operative to develop a bursting load in the die which cracks or splits the die as the casting is drawn downwardly.

In addition, the occurrence of bleeding and the subsequent solid wedge formation developed, frequently causes

a marred or ribbed finish on the surface of the casting, frequently referred to as a washboard surface. This occurrence is an undesirable condition.

In contrast to the condition just described and in accordance with the principles of the present invention, when sufficient pressure is maintained in the gap between the forming die and the exterior surface of the cast cross section, specifically in the region of the solidification front, bleeding is virtually eliminated. As stated previously, the introduction of pressure in this area at a value sufficient to counteract the head pressure of molten metal above the curve 27 operates in combination with the light or gentle support provided by the skin 32 to preclude bleeding and to confine the low melting constituents within the skin to develop a smooth transition of all constituents from the solid to the liquid phase as shown by the curve 28 of the left side of FIG. 3.

An alternative arrangement for controlling pressure is shown in FIG. 2 wherein the molten metal crucible is formed with a closed or fluid-tight cover 41 and the desired pressure differential across the solidification front is achieved by evacuating the closed crucible under the control of an appropriate vacuum pump in turn controlled by a pressure sensing unit 42 which continuously measures the pressure developed by the head of metal within the crucible. In effect, sufficient vacuum is maintained within the closed crucible to effectively float the molten metal thereby eliminating the head upon the solidification front. This arrangement allows normal atmospheric pressure to counterbalance the head of pressure.

In both the FIG. 1 and FIG. 2 embodiments of the invention suitable take-up rolls 43 and quenching nozzles 44 are utilized to withdraw and to quench the cast metal.

In a typical casting run, a crucible of 500-pound capacity is fitted with a graphite die and placed in a gas-heated furnace. A die opening $\frac{1}{2}$ " x 6" is used to cast a $\frac{1}{2}$ " x 6" bar. Initially, a dummy bar fitted with a stopper is inserted in the die through the withdrawal mechanism to seal the die opening. A charge of metal such as 88-4-4-4 Brass (88% Cu; 4% Zn; 4% Pb; 4% Sn) is poured into the crucible and held at 2000° F. This alloy solidifies at 1850° F. The crucible may then be covered and sealed to permit pressure equalization across the die opening by counterbalancing the head of molten metal. Cooling sprays directed against the emerging metal bar are then actuated and the operation of the withdrawal mechanism (not shown) is started. In the instance of the $\frac{1}{2}$ " x 6" bar, a withdrawal rate of 7" per minute may be attained with a spray water cooling rate of 6 gallons per minute. Operation is continued until the charge of metal in the crucible is exhausted and as the pressure head decreases the counterbalancing pressure is kept in equilibrium therewith.

It is anticipated that a variety of embodiments of the apparatus and process steps disclosed may be devised without departing from the spirit and scope of the present invention.

What is claimed is:

1. In a method of continuously casting metal in a forming die containing two different melting constituents including feeding said metal in molten condition through an apertured die, cooling the molten metal so as to develop a solidification front within the die, said solidification front characterizing a region in said die within which the molten metal changes to a solid metal, a high melting constituent of said metal freezing first to develop a peripheral skin, said skin connecting said die with completely solidified metal below said region, said skin being susceptible of rupture as a result of a head of said molten metal: the improvement in combination therewith which comprises the step of supporting the skin by means of subjecting said skin to sufficient fluid pressure effective to counterbalance said head whereby the skin is precluded from rupturing, said degree of support being measured by the head of molten metal above the solid metal.

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2. In the continuous conversion of molten metal into solid metal where the metal contains a plurality of molten constituents having different solidification temperatures which comprises passing said molten metal continuously through a forming die, said die imparting a first cross sectional area to the metal while substantially molten, said first area blending to a reduced cross sectional area at a point where the metal is substantially all solid and in spaced relationship to the internal wall of said die; the improvement in combination therewith which comprises freezing a high melting constituent to establish a rupturable skin about the metal in the region between said two areas, and applying sufficient fluid pressure to the exterior of said skin in said region operative to support the skin in said region against and to prevent rupture, said degree of support being measured by the head of said molten metal above said solid metal.

3. In a method of casting metal vertically wherein a reservoir of molten metal having high and low melting constituents is maintained in an open ended continuous casting mold and a bar of solidified metal is continuously withdrawn from said mold, a dendritic solidification front comprised of a solid phase of said high melting constituents and a liquid phase of said low melting constituents formed between said molten and said solidified metal, with a portion of said front adjacent the internal wall of said mold disposed in spaced relationship to said mold wall and subjected to the hydrostatic head of said molten metal; the improvement in combination therewith which

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comprises controlling the exudation under said head at said portion of said liquid phase from said front through the network defined by the high melting constituents in said solid phase into the annular space defined between said portion and said mold wall by maintaining a sufficiently greater gaseous pressure on said portion than on said molten metal to prevent said exudation, said pressure being measured by said hydrostatic head of molten metal.

4. The method of claim 3 wherein said exudation is controlled by applying said greater pressure to said portion and exposing said molten metal to atmospheric pressure.

5. The method of claim 3 wherein said exudation is controlled by applying a vacuum to said molten metal and exposing said portion to atmospheric pressure.

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