METHOD AND APPARATUS FOR CASTING METAL

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This invention relates to a method and apparatus for continuously casting metals.

My invention provides a method and apparatus for passing a stream of molten metal into a die and extruding or extracting a continuous member of solid or semi-solid metal from the other end of the die. I am aware that methods and apparatus for a similar purpose have been herebefore proposed but where they purported to deal with metals of high melting temperature, such as steel and the like, they were of no practical or commercial value because, if successful at all, after a brief operation the apparatus broke down.

One of the purposes of the present invention is to cure these defects of prior apparatus and to provide apparatus which is capable of continuously casting metals and alloys of high melting points on a commercial and practical basis.

One of the purposes of the present invention is to provide a novel die in which the molten metal is cooled and a skin cast upon it, and wherein a substance is provided between the walls of the die and the cast metal which performs a number of functions, among them being the lubrication of the passage of the metal through the die, the filling of the spaces where the solidifying metal draws away from the die by a self-accommodating material which maintains efficient heat conductivity between the metal and the die, the protection of the walls of the die from direct contact with and heat radiation from the metal, and the maintaining of a suitable surface on the cast metal. One preferred form of such a lubricant or self-accommodating die lining material is graphite, which is a good black body and performs the function of absorbing and conducting heat from the solidifying metal to the walls of the die while reflecting back to the metal little of the heat received, this in addition to performing all of the functions outlined just above.

Another feature of the present invention is the provision of apparatus for very carefully controlling the temperature of the metal during all stages of the casting process. This temperature control extends to the metal in the reservoir from which molten metal is fed to the casting or chilling apparatus and to the various parts of the apparatus as the metal passes through it. By such close control the metal may be cast from a point just slightly above the solidus, giving certain preferred characteristics to the solidified metal where desired. Also the rate of contraction and the correspondence of the sectional area of the cast metal to the die is assured at all points during the passage of the metal through the die. This assures a predetermined space for accommodating the die lining material such as graphite mentioned above.

Another feature of my process and apparatus is the special arrangement at the molten metal receiving end of the die where special means is provided for confining the molten metal while the first skin is being formed thereon. This feature involves the use of a member or means which is hereinafter termed a “liner,” the use of which is very important in controlling the formation of the first skin on the solidifying metal. By the use of varying types of liners the texture of this skin may be varied as will hereinafter appear. The use of such a liner contributes to the long life and commercial practicability of my die casting process.

Another object of the present invention is to provide novel means for insuring the steady and continuous passage of the metal through the die, both by means of the hydrostatic pressure of molten metal supplied to the die or by the use of compressed fluids aiding in forcing the metal through the die, together with the use of pinch rolls or other pulling apparatus at the exit end of the die.

Another object of the present invention is to protect the quality of the metal at all points throughout the apparatus. For instance, the molten metal is held preferably in a reservoir of sufficient capacity to provide a steady stream of molten metal to the die apparatus at a substantially constant temperature. Such a reservoir is also of sufficient capacity to permit the molten metal to lie quietly so that slag and other occluded foreign material may have time and opportunity to rise to the surface where it may be disposed of. Another novel feature which protects the quality of the metal is the provision of non-oxidizing and, where desired, a reducing atmosphere about the metal as it passes into the die and as it passes through the die. This prevents the formation of oxides during the course of the casting process which oxides might be occluded in the solidified metal or might appear upon the surface thereof with not only bad effects upon the
metal quality but deleterious effects upon the walls of the die.

Another function of the application of non-oxidizing or reducing gases about the solidifying metal as it passes through the die is the protection which certain of such gases may provide for the walls of the die and the aid of such gases as for instance hydrogen, in maintaining heat conduction between the solidifying metal and the walls of the die.

Another novel feature of my apparatus is the provision of nonoxidizing or reducing gases in such a way in the apparatus that they not only provide the advantageous features pointed out above but in addition may be arranged to bubble through the molten metal in the feeding reservoir thereby producing a metal agitating or cleaning result in that reservoir.

Another novel feature of my invention is the manner in which the lubricant or other self-accommodating die lining material is fed to the die. My invention also includes the maintenance of such lubricant or other material under sufficient pressure to fill the interstices between the metal and the walls of the die without distorting or damaging the solidifying skin of the metal passing through the die.

Another novel feature of the present invention is the careful construction of the walls of the die to conform to the cross section of the solidifying and contracting metal passing therethrough.

Another novel feature of my invention is the provision of a metal constricting portion at the exit end of the die whereby to refine the crystalline structure of the metal at that point and to protect the semi-solid metal in the die from the pulling effect of the pinch rolls or other pulling apparatus which may be used to aid in the passage of the metal out of the die.

Other advantages and novel features of my method and apparatus will appear hereinafter from the specification and the drawings and the essential features thereof will be summarised in the claims.

In the drawings:

Fig. 1 is a central section showing typical apparatus for carrying out my novel casting process with certain portions thereof relative to temperature control being shown somewhat diagrammatically;

Fig. 2 is an enlarged central section through the die portion of Fig. 1 and along the line 2—2 of Fig. 3, with lubricant supply and die temperature control shown diagrammatically;

Fig. 3 is a sectional view along the lines 3—3 of Figs. 2 and 4;

Fig. 4 is a sectional view along the line 4—4 of Fig. 3;

Fig. 5 is a fragmental detail section (somewhat distorted) of a portion of the die wall showing a manner of introducing the lubricant or other material between the solidified metal and the walls of the die;

Fig. 6 is a wiring diagram showing one manner of connecting up equipment for automatically controlling the temperature of the molten metal in the reservoir in accordance with a predetermined temperature of metal passing to the die;

Fig. 7 is a section similar to Fig. 3 showing a modified form of die for forming shapes directly from melt metal.

In the apparatus illustrated in Figs. 1 to 6, a reservoir 10 is provided for receiving and holding molten metal before it is fed to the casting apparatus. Such a reservoir will be supported upon suitable building structure (not shown) and supplied with molten metal from a ladle hand held by an overhead crane, or by any other suitable apparatus. The reservoir 10 is of such capacity that a body of metal is held in a substantially quiet state and at a substantially constant temperature for feeding to the casting apparatus. The device of Figs. 1 to 6 illustrates apparatus for casting slabs and where such slabs are of normal heavy section, such as 2 to 6 inches thick and 12 to 36 inches wide or wider, the reservoir 10 would hold 20 to 60 tons or more of metal to provide the highest quality of cast metal.

The reservoir illustrated comprises a steel or cast iron shell provided with an inner refractory lining 11 adapted to stand the heat of the metal in the reservoir for long periods of time without substantial deterioration, or objectionable effect upon the metal in the reservoir. For instance, if molten steel is to be handled, the lining might be of chrome brick. If the metal in the reservoir is to be held at a carefully determined temperature and if skulls in the metal are to be avoided, some heating means should be provided thereof. In the form shown a induction coil 12 is built into the reservoir protected by a heat protecting refractory layer 13 between the coil and the inner lining and preferably having also outside of the coil a heat insulating layer 14 next to the shell. The reservoir may also be provided with an overflow spout (not shown) near the top so that upon an accumulation of slag in the reservoir the level of the metal therein may be raised and the slag run off through the spout.

Suitable openings are provided for removing metal from the bottom of the reservoir 10. A main opening 16 leading to the casting apparatus is closed by the usual stopper 16 which is manipulated by the stopper handle 17. Also preferably an auxiliary or emergency outlet 16 is provided in the bottom of the reservoir closed by the stopper 16 which may be manipulated by the handle 18. If for any reason the reservoir must be emptied other than through the opening 16, the outlet 16 is available through which the metal in the reservoir might be passed to another ladle or to a series of molds if necessary to discontinue the operations through the continuous casting apparatus.

The metal passes from the feed reservoir 10 through a passage 21 to the casting apparatus. This passage is preferably lined also with a refractory lining and preferably also supplied with a separate electric induction heating coil 22 supplied from a suitable source of current. This is to ensure that the passage 21 remains open at all times.

The die casting apparatus is indicated generally at 23 and comprises an upper chamber portion 24 adapted to be connected to the passage 21 to receive metal from the reservoir 10. Below this is the die portion 25 where the initial solid skin is formed on the metal. Again below this is the die portion 26 for the further solidification of the metal on its passage therethrough. At the mouth of the die is the portion 27 which is somewhat restricted so as to provide a metal working effect and to protect the metal farther back in the die from any pull exerted upon it by the extracting apparatus. This portion also helps to keep the shape centered in the die. A pair of pinch rolls for extracting is indicated
somewhat diagrammatically at 28, it being understood that these will be provided with a suitable drive and with means for varying the position of the rolls on opposite sides of the slab of metal passing between them. Suitable structural framework (not shown) will be provided for supporting the die casting apparatus.

Where the passageway 21 leads to the upper chamber 24 of the die casting apparatus, a structure is preferably provided enabling an inspection of the flow of metal into the die so that the operator may determine both the level of the metal in the die and the temperature of the flow of metal to this end an upwardly extending passageway 29 is provided at this upper end with a suitable inspection window 30 adapted to withstand the high temperatures present. Through this window the temperature of the metal may be read by an optical pyrometer if desired or a light sensitive cell may be placed there as indicated at 31 for the purpose of automatically regulating the temperature of the metal in the reservoir in accordance with the temperature of the metal flowing to the die. A suitable control circuit for this purpose is indicated in Fig. 6 and will be hereinafter explained.

Preferably the die casting apparatus is connected with the metal reservoir and associated parts in a manner to be detached if necessary.

To this end the case 32 housing the passageway connected with the reservoir 44 is provided with outwardly extending flanges 33 at the lower end, which flanges are bolted at 34 to brackets 35 of the casing 36 surrounding chamber 24. This die portion preferably has a refractory lining 37.

The die casting portion 25 comes in contact with the molten metal during the formation of the first outer skin. This die portion has water passages 25a through which a stream of water is continuously passed for the purpose of chilling the die to whatever extent may be desirable. Between the die portions 25 and 26 a machined joint 38 may be provided, or a gasket of suitable material, for instance asbestos, may be inserted there. These two die portions are secured together by their flanges as by the use of bolts 39, clamps or the like. One of the novel features of my model is that the metal 40 in this upper portion of the die where the molten metal first comes in contact with the inner walls thereof. This liner must be a good heat conductor and have good refractory characteristics and should have little chemical action upon the metal in contact with it. Preferably also for long life it should be highly resistant to abrasion of the molten metal. Quite a number of materials are suitable for this liner, among them tungsten carbide, silicon carbide, graphite, graphite in copper, graphite and carbonum, carbonum alone, chrome brick, chrome copper alloys, nickel copper alloys, such as "Inconel" with or without metallic oxide additions, high chrome steels, Monel metal with or without chrome oxide, Monel metal with graphite, and similar materials.

It is preferred that the thickness 48 as thin as is consistent with long life so that the die would respond therethrough to the cooled copper wall will be sufficient to form a skin on the metal. I find that the surface qualities of the metal may be varied according to the choice of the type of liner 46. For instance a graphite and carburnum liner will give a rough texture to the surface while Monel metal or tungsten carbide liners give a smooth surface.

The die portion 26 may be of one or more sections. As illustrated I have shown one section split along a vertical plane into two halves which are machined and bolted together by their flanges 28c. This die portion is provided with water cooling passages 28a. The metal-contacting inner faces of the copper walls 28b if desired may be formed of graphite in copper so as to harden and increase the life of the inner surface of this portion of the die.

While not absolutely necessary to the practical operation of my die casting operation, I prefer to supply at the exit end of the die the metal constricting portion 27. As shown here, this is preferably of a harder material than the die portions 28. For instance this might be of a harder copper than the rest of the die or preferably would be of chrome nickel steel or the like and provided with water cooling passages 27a. The purpose of this metal constricting portion at the end of the die is to draw the metal while it is hot, producing a welding effect on any openings in the casting while they are still in a nonoxidized state to produce a crystal refining action in the metal; and to protect the semi-solidified metal in the interior of the die from the pulling effect by which the substantially solidified metal is pulled out of the die as for instance by the pinch rolls 46. This prevents any tearing of the semi-solidified metal in the upper portion of the die.

The die portions 26 and 27 may be secured together as by their outwardly extending end flanges and by bolts 41.

Preferably means is provided for controlling the flow of water through the water cooling passages of the die as to provide a constant rate of cooling of the metal as it passes through the various portions of the die. If this is done the physical characteristics of the solidified metal will be held constant because of the constant cooling characteristics throughout the length of the die as the metal progressively passes therethrough.

To this end I have indicated somewhat diagrammatically in Fig. 2, a manner of sectionalizing the water cooling of the die and the automatic control of the temperature of each section. To this end the cooling passages 25a, 26a, and 27a, are supplied with a cooling medium such as water or the like from source 42, and discharge is at 43. Preferably each of these die cooling sections is provided with means for controlling the flow of cooling medium in response to the temperature of the die walls so as to maintain constant casting conditions. A thermostatic valve 44 is operated by a solenoid 48 which is controlled by a relay 46 which in turn is responsive to the thermal mostat pyrometer 47 having a pyrometer element embedded in the wall of the die. A suitable power source is connected at 48 for operating the thermostatic valve and the arrangement of the parts is such that if the temperature of the pyrometer element 47 rises above a predetermined point, the valve 44 will be opened to admit more cooling medium to the cooling passages, and upon the pyrometer dropping below the predetermined high point the solenoid 48 will be deenergized permitting the valve 44 to return to a predetermined minimum setting. Other specific arrangements of the control system for the cooling medium will occur to those skilled in this art and any suitable system is within the scope of my invention.

A suitable control system for holding the metal in the reservoir 18 at a substantially constant temperature is shown in Fig. 6 where the electric furnace high frequency coil 12 is indicated dia-
grammatically as being supplied with current of high voltage and high frequency from a suitable source $\phi$. In the supply line for coil $f_2$ is a relay $R_1$ having a contact $c_1$ and a contactor arm $b_2c$ controlled by the relay coil. The contact $b_2c$ is shown diagrammatically and will be one suitable for the current and voltage handled. When the contactor arm closes, the circuit from source $\phi$ supplying coil $f_2$ will be closed as is readily understood from the diagram. The light sensitive cell is positioned as shown at $s_1$ in Fig. 1 is here indicated in diagram having its light sensitive plate $s_{1a}$ connected by conductor $s_{1b}$ with the grid $s_2$ of a triode $s_2$. The current for operating this control circuit comes from the secondary $s_3$ of a transformer connected with a suitable source of alternating current. A rectifier $s_4$ provides a direct current between the conductors $s_4$ and $s_{5a}$. The line $s_5$ is connected through lines $s_6$ and $s_{7a}$ so as to energize the coil of relay $s_6$ and $s_{7a}$ is connected with the anode $s_{2b}$ of the triode. The cathode $s_{2c}$ is connected through resistance $s_3$ and line $s_8$ with line $s_{1a}$ and is also connected through line $s_9$ and resistance $s_5$ with the line $s_{1a}$. Between lines $s_{1a}$ and $s_{1b}$ is connected the variable resistance $s_8$. The line $s_{1b}$ connects line $s_{1b}$ and the other terminal of the light sensitive cell $s_{1b}$. By suitably varying the aperture of the light sensitive cell and the adjustment of the variable resistance $s_3$, the cell may be set to energize the circuit when the temperature of the metal flowing into the die casting apparatus drops below a predetermined point so as to close the relay $s_4$ and supply current to the high frequency coil $f_2$. On the other hand, if desired the cell might be set to provide high frequency current to the coil $f_2$ until the temperature of the metal flowing into the die casting apparatus passed a predetermined high point at which time the light sensitive cell would be energized and arranged to break contact at relay $s_4$ instead of making contact as illustrated in Fig. 6. It will be understood of course that two light sensitive cells might be supplied, one to cut off the supply of current to coil $f_2$ if the metal passed above a predetermined high point and another to turn on the current in coil $f_2$ if the temperature of the metal passed below a predetermined low point. Such control systems are well known and further description is not thought necessary here.

Certain problems are inherent in the forming of continuous ingots, slabs, billets, shapes and the like direct from molten metal. The cast piece must be formed within die walls open at each end. Molten metal is fed to the die at one end and the cast piece removed at the other end either continuously or intermittently. Heat transfer must be indirect, that is, from the metal being cast through the die wall to the cooling medium. Most metals shrink or contract when cooled. This results in a drawing away of the metal from the cooling walls of the die leaving an air gap across which heat transfer is greatly retarded.

It has been assumed, also, that one is faced with the dilemma of the air gap between the cooling walls and the hot metal (as mentioned above) with consequent loss of heat transfer, or die walls which are arranged to be in close contact with the hot metal with consequent friction so great that movement of the cast piece out of the die is almost impossible.

My answer to this problem is to provide between the outer skin formed on the cast metal and the die wall, a self-accommodating material of relativley high thermal conductivity so as to fill and keep filled along the length of the die the shrinkage cavity caused by the cooling of the cast metal. At the same time, this material may be so selected that it has lubricating properties even at the temperature of steel just below the solidus. Graphite is such a material. Thus thermal conductivity is increased and friction reduced.

The equation for heat transmission is as follows:

$$Q = \frac{K(T_1 - T_2)}{d}$$

Here $Q$ represents the quantity of heat passing through a material of area $A$ and thickness $d$ and having a coefficient of thermal conductivity $K$ in the time $t$, where the opposite faces of the material are subject to temperatures $T_1$ and $T_2$ respectively.

The coefficient $K$ for graphite approaches that of steel at high temperatures just after solidifying. Therefore, if graphite fills the space left by contraction of the first-formed steel skin away from the die wall, the transfer of heat from the metal to the wall will continue at almost the same rate even when the metal was in direct contact with the wall. Whereas, if there were an air gap between the metal and the die wall, the thermal conductivity of the air would be approximately one-fiftieth of the graphite.

Another effect of my improved method and apparatus is an increased uniformity in the cast metal. Without the use of my improved apparatus the contraction of the metal from the walls of the die leaves the metal in contact with the walls at some point and out of contact at other points; giving a very irregular and nonuniform cooling effect with resultant inequalities and imperfections in the metal and very seriously affecting the life of the die.

For all of the various reasons previously set forth herein such as loss of heat conducting contact between the metal and the die, fire cracks in the cast metal due to heat radiation and other reasons elaborated above, I prefer to keep continuously filled the interstices between the solidified skin of the cooling metal and the inner walls of the die by a suitable material which will accommodate itself to the variations of the size of the cast metal. Various materials are suitable for this purpose, such as graphite, coke, aluminum oxide, chromic oxide, iron oxide, talc, lime, and like materials or suitable combinations of the above. Some of these materials may be mixed with glycerine or the like to prepare them in suitable form for application.

I find that above named filling materials are best introduced between the metal and the die wall in a finely divided or powdered form either dry or carried by a suitable vehicle. Hereafter, in the specification and claims, the use of the term "powdered" does not necessarily refer to powder in the dry form but finely divided material no matter how it is introduced into the die.

My invention includes all suitable filling materials, as I believe I am the first to use finely divided solid material at a point in the die where the first skin has formed on the metal and I desire to include all suitable materials which will withstand the high temperatures met with at this point and yet which will accommodate itself to the interstices and changing movements between the skin of the metal and the die walls which will maintain substantially continuous heat conducting contact between the congealing metal and the die walls.
Where steel is being continuously cast in my novel apparatus I find graphite is particularly applicable because it resists the intense heat very well and absorbs and conducts heat to the die walls without being melted. The graphite has the additional merit that it contributes to a smooth surface on the cast steel, remains on the cast steel as a protective film while it cools, and protects the die from heat otherwise radiated from the steel which would produce fire cracks and deterioration of the die walls.

After the first thin skin has formed on the metal and it shrinks away from the die wall, if an air gap is present as in the prior art, the thin skin is insufficient to support the intermediate molten mass and the pressure of molten metal above it. The skin is thus subject to distortion and may rupture. Also, if conductivity between the new skin and the cooler die wall is broken by the air gap, the skin is reheated from the melting point of graphite. In the case of graphite bleeding, this will produce surface defects and possibly a spongy center. My invention supplies a plastic material which fills this space where the air gap was in the prior art between the thin skin and die wall. This plastic material maintains thermal conductivity between the metal and die so as to prevent reheating of the skin, and supports the thin skin so as to prevent distortion and rupture.

Any suitable means may be provided for applying the self-accommodating lining material illustrated diagrammatically in Fig. 2. Here a spiral screw 65 is housed in a cylindrical casing 66 supplied with lubricant, and the gear 69 is driven from a variable speed motor 68. This will supply lubricant under pressure to the conduits 70, the pressure being varied by varying the speed of motor 68. One arrangement of these conduits is shown in the illustration, and such a device may be used so long as the lubricant is fed to all sides of the cast piece under sufficient pressure to enter the spaces between the cast piece and the die walls.

For other lubricants a plunger pump may be used having a bypass opening at a predetermined pressure so that the pump may be run to supply lubricant at any desired pressure. Other materials may be supplied from reservoirs of lubricant under pressure such as that supplied from a power driven plunger or compressed air to supply the lubricant through suitable conduits 70 to the die. Certain of the lubricants may be mixed with glycerine or other suitable liquid to give them sufficient fluidity.

One form of passageway which I have conceived as suitable for applying the lubricant graphite is illustrated in Fig. 5 where a groove 71 extends substantially continuously around the inner face of the die wall and is supplied at spaced points through conduits 72 in the die walls connected with the pressure conduits 70 heretofore described. Such a construction suffices to maintain a continuous supply of graphite about the inner periphery of the die at each point selected. The pressure on the lubricant will be so regulated that at the point 73, Fig. 5, the skin formed on the solidifying metal 74 will not be deformed to any great extent. In other words the graphite will form substantially a continuation of the inner face of the die at this point and a small film will be carried alongside the metal as indicated at 75 filling the interstices between the metal and the die wall. This view will illustrate the formation of the lubricant film between the cast piece and the die wall. As shown in the various views all of the lubricant passages will preferably be arranged with smooth curves so as to interrupt the flow of the lubricant.

To protect from oxidation the metal flowing from the reservoir 76 through the passage 77 to the die casting apparatus, I may supply to the upper end of the die casting apparatus a suitable gas under pressure as at the connection 78, Fig. 1. Suitable gases for this purpose are for instance hydrogen, nitrogen, carbon monoxide, carbon dioxide and others which will occur to those skilled in this art. These gases may simply be inert gases as nitrogen or may have a reducing effect as hydrogen. In the case of reducing gas, the oxidation of the molten metal previous to its solidification would simply be prevented. In the case of hydrogen not only would this same effect be produced but any small amounts of metallic oxides present in the upper portion of the die casting apparatus would be reduced. This prevents the formation of oxides in the die casting apparatus which would have a bad effect upon the physical characteristics of the metal and also upon the surface characteristics of the cast metal and the die walls.

The gas supplied at source 76 may be under sufficient pressure to create considerable hydrostatic pressure in the upper portion of the die so as to aid in the passage of the metal through the die and to give a compressing effect upon the cast metal so as to reduce the grain structure thereof. I believe it is novel to act upon the one end of the cast piece with gas under pressure while pulling the other end of the cast piece by the pinch rolls 23 and lubricating the passage of the metal through the die. I thus powertfully urge the cast piece through the die without tearing the metal.

The gas supplied from source 76 may be placed under sufficient pressure to bubble through the opening 16 as the stopper 18 is manipulated and of sufficient head to bubble up through the metal in reservoir 10 to exert a cleaning effect upon the metal in the reservoir. For instance if hydrogen gas or carbon monoxide were thus passed upwardly through the reservoir it would have a tendency to clean oxides from the metal.

The gas supplied in the upper portion of the die casting apparatus may be of sufficient pressure to pass downwardly between the metal and the inner walls of the die, thus continuously protecting the surface of the solidifying metal from chemical action or from oxidation. At the same time if the gas was hydrogen it would not detract greatly from the heat conductivity between the metal and the die as hydrogen is high in heat conductivity. At the same time this gas under pressure between the metal skin and the walls of the die would tend to have a sealing effect, that is it would reduce friction between the metal and the die. A reducing or non-oxidizing gas may be introduced at one or more of the 76.
conducts 70 in place of or in addition to the lubricant.

A suction pump may be attached at 78 instead of the metal supply. This would create a vacuum in the upper portion of the die with consequent removal of oxygen and variation in characteristics of cast metal.

Nothing has been said in detail with regard to the pinch rolls 26 or other apparatus to take care of the metal after it leaves the die as such apparatus is well known. Generally there would be suitable guides and other rolls to handle the metal after it passes from the die casting apparatus.

I do not restrict myself to either partially or completely solidifying the metal before it emerges from the die. My process may be operated either way but it is entirely feasible if the metal section is not too thick to have the metal strip substantially completely solid when it emerges from the die. The length of the die may be varied to obtain the result desired.

While my description has been limited chiefly to the casting of steel in the form of a slab in a vertically arranged die, I desire it understood that I do not limit myself to any of these particulars. My improved process and apparatus may be used for the continuous casting of various other metals and other sections and with the die in various positions. For instance, in Fig. 7 I have roughly illustrated a section similar to Fig. 3 and having an inner die space for casting a full section which in practical operation would be slightly larger so as to permit a final rolling operation to exact size. The lubricant supply means is diagrammatically illustrated at 77 and performs the same function as the similar parts previously described.

The walls of die portion 26 will be shaped according to the characteristics of the metal being cast, always bearing in mind that if the metal does not shrink enough to allow space for the lubricant film, then the die walls will flare outwardly enough to provide such a space.

In use, the process is started by placing a metal bar substantially of the cross section of the die exit end in the die with its projecting end between the pinch rolls. Such a bar might be heated to weld with the metal first cast, or would carry projections at its inner end adapted to become the core when the cast is then initiated by manipulating stopper 16 and, after allowing time for the first poured metal to unite with the starter bar, the pinch rolls are started. The speed of the pinch rolls is regulated as desired and the level of the metal in the die controlled by manipulating stopper 16 as advised by the conditions observed through the inspection window.

My improved method and apparatus may be operated intermittently or continuously. The latter gives greater uniformity in the cast metal.

It results from the use of the above described process and apparatus that metal may be continuously cast on a commercial scale with very high quality as to internal physical characteristics and surface characteristics of the cast metal.

The protection afforded the walls of the die gives a material benefit to my apparatus such as has not been heretofore known. All of the factors herein disclosed contribute to one end, namely, that metal, even of high melting point, may be continuously cast for an indefinite length of time because I have overcome those difficulties which heretofore caused stoppage after comparatively short lengths had been cast.

Where the metal cast is steel it has few or none of the defects heretofore found in usual casting methods. For instance there is no pipe in the steel because the center of the cast section is continuously supplied with metal at all times until it is congealed. The center is protected against oxidation and if there should be any cavity in the center it would be closed and welded by the constricted exit end 27 of the die. Blow holes are reduced to a minimum or entirely eliminated because of the continuous supply of metal and the prevention of oxidation of the metal so that any small holes if formed will be welded together at the exit end of the die. A very fine crystal structure results from the fast freezing which makes for small crystals, and the uniform casting conditions provide uniform crystal structure throughout the length of the metal strip.

Because of the close control of the temperature of the metal throughout the entire process the steel may be cast from a mushy state just above the solidus if desired, thus further reducing the freezing time. The fast freezing provided gives little chance for segregation and the constant progress of the freezing zone gives a uniform distribution of whatever ingredients settle out. Non-metallic inclusions are practically eliminated because the mold is filled with clean metal in the quiet pool of the feed reservoir. No inclusions are possible from dirt in the molds because my casting apparatus is continuously filled with clean metal and no dirt can get in. There is no soldier, or cracks in the skin of the cast metal because of the smooth lubricated walls and the uniform movement during freezing prevents stresses in the skin. The constricted die end 27 prevents the pull of rolls 28 tearing the metal in die portion 26. There are no scabs from splashes during pouring because the mold is filled slowly and uniformly without much dropping of metal and the upper portion of the die is hot enough to remelt splashes if any occur.

It should be clearly understood that if the metal does not shrink sufficiently to provide space for efficiently introducing the self-accommodating die lining material, then the die walls will be so proportioned as to provide the requisite space. This may also be the case if the die is made long enough to have the metal fully solidified at its exit from the die and flow is then passed through the passage of metal through such a die, the shrinkage may be very small. Here again the die walls will be shaped to permit introduction of the plastic die lining material, regardless of the shrinkage of the cast metal.

There is no good authority for the theory that considerable relative movement takes place between a die and metal cast in it. There is expansion and contraction of the die walls due to the effect of the hot metal upon the colder walls. There is expansion and contraction of the congealing metal also, because wherever it touches a cold wall it will immediately shrink away only to later expand outwardly due to reheating or due to the ferrostatic pressure of the still molten interior even when the skin is of substantial thickness. My invention for the first time supplies material benefit to my apparatus such as has not been heretofore known. All of these interstices no matter how they vary so that the skin of the congealing metal is supported and protected and the walls of the die are kept from direct contact with the hot metal so that the walls are not galled or abraded or subjected to fire-cracks and hot metal can not stick to the wall.

In certain of the claims applicant has defined
the die lining material as facilitating the casting of the metal in the die. By this term "facilitating" applicant means to cover material which supports the tender skin on the metal against sagging and rupture, which maintains sufficient heat conductivity between the skin and die wall to prevent reheating and remelting of the skin and maintains continuous progressive cooling, which improves and protects the metal surface, which protects the die surface, or which may lubricate the passage of the metal through the die.

What I claim is:

1. Apparatus of the class described comprising a die having a passage therethrough, means for passing molten metal into one end of said passage, said die having walls surrounding said passage and adapted to remove heat from said metal to form a solid skin thereon within said passage, a refractory heat-conducting liner on said walls at the entrance end of said passage in contact with said molten metal for forming a first skin thereon, said liner ending at that point where the first skin has formed, whereupon said metal shrinks away from the walls of said die passage, and means for thereafter filling the interstices between said metal skin and die walls with a heat-resistant material.

2. Apparatus as in claim 1 wherein said filling material has lubricating properties.

3. The method of continuously casting metal comprising continuously passing metal through a hollow chilled die at a velocity permitting said die to congeal said metal from a molten to at least a partially solid state whereby the metal forms an outer skin from contact with said die during the first portion from said passage therethrough, and thereafter continuously supplying between said skin and die a finely divided solid material capable of remaining solid during the casting operation and capable of accommodating itself to the interstices between the cast metal and die wall, whereby to protect the walls of said die from abrasion and galling, and to protect the surface of the congealed metal from run-outs and abrasion.

4. Apparatus of the class described comprising a die having a passage therethrough, means for passing metal through said die, said die being constructed to conduct heat away from said passage at a rate sufficient to form a solid skin on said metal at the exit end of said passage when substantially molten metal is fed to the entrance end of said passage, the relation between said congealing metal and said die being such that there is a space between said metal and die at the point where the first skin is formed on the surface of the metal, and means for supplying to said space at said point a powdered material facilitating the casting of the metal in said die.

5. Apparatus as in claim 4 including means for supplying to said space a gas for protecting said powdered material against deterioration.

6. Apparatus of the class described comprising a substantially rigid die having a passage therethrough, means for passing metal through said die, said die being constructed to conduct heat away from said passage at a rate sufficient to form a solid skin on said metal at the exit end of said passage when molten metal is fed to the entrance end of said passage, means for supplying a graphite compound between said die and the metal passing through it at a point where a skin has formed on said metal and said die maintains a substantially heat-conducting contact between said skin and said metal maintain heat-contacting contact between said skin and die.

7. Apparatus of the class described comprising a die having a passage therethrough, means for passing metal through said die, said die being constructed to conduct heat away from said passage at a rate sufficient to form at least a solid skin on said metal at the exit end of said passage when substantially molten metal is fed to the entrance end of said passage, and means for supplying between said skin and die, at points spaced on said die, finely divided solid material facilitating the casting of the metal in said die and adapted to fill all spaces between said skin and die, last named means being adapted to vary the pressure at said spaced points, whereby the pressure on said material may be coordinated with the position and condition of the solidifying metal in the die.

8. Apparatus of the class described comprising a die having a passage therethrough, means for passing metal through said die, said die being constructed to conduct heat away from said passage at a rate sufficient to form at least a solid skin on said metal at the exit end of said passage when substantially molten metal is fed to the entrance end of said passage through a groove in the inner wall of said die located at a point where a skin has formed on said metal, and means for supplying a flowable graphitic compound to said groove.

9. The method of continuously casting metal comprising continuously passing metal through a hollow chilled die at a velocity permitting said die to congeal said metal from a molten to at least partially solid state whereby the metal forms an outer skin from contact with said die during the first portion from said passage therethrough, and thereafter continuously supplying between said skin and die a finely divided solid material capable of remaining solid during the casting operation and capable of accommodating itself to the interstices between the cast metal and die wall, whereby to protect the walls of said die from abrasion and galling, and to protect the surface of the congealed metal from run-outs and abrasion.

10. In the method of casting metal continuously comprising feeding molten metal from a reservoir through a substantially gastight passageway to one end of a die which is open at both ends, while chilling the metal in said die and drawing it out the other end of said die, the step of supplying to said passageway a gas under sufficient pressure to cause some of it to pass into the molten metal in said reservoir.

11. Apparatus of the class described comprising a die having a passage therethrough, means for passing molten metal into one end of said passage, said die having walls surrounding said passage adapted to remove heat from said metal to form a solid skin thereon within said passage whereupon said metal shrinks away from the walls of said die passage, and means positioned between the zone where said skin is normally formed and the exit end of said die to fill the interstices between said metal and die wall with a readily conformable material for supporting the solidified surface of the metal being cast, from substantially the zone of surface solidification to the exit end of the die end for facilitating the movement of the metal out of the die.

12. The method of continuously casting metal which consists of feeding molten metal from a reservoir through a substantially gastight passageway to one end of a hollow chilled die at a velocity permitting said die to congeal at least the outer surface of the metal within the die whereupon said metal shrinks away from the walls of said die passage and filling the interstices between said congealed
surface and said walls from substantially the congealing zone to the exit end of said die with readily conformable material for supporting the solidified surface of the cast metal away from the die walls and for facilitating the movement of the metal out of the die.

13. Apparatus of the class described comprising a die having a passage therethrough, means for passing molten metal into one end of said passage, said die having walls surrounding said passage adapted to remove heat from said metal to form a solid skin thereon within said passage, and means positioned between the zone where said skin is normally formed and the exit end of said die to supply continuously a material for lubricating the solidified surface of the metal being cast from substantially the zone of surface solidification to the exit end of the die and for facilitating the movement of the metal out of the die.

14. Apparatus of the class described comprising a die having a passage therethrough, means for passing molten metal into one end of said passage, said die having walls surrounding said passage adapted to remove heat from said metal to form a solid skin thereon within said passage, there being ports through said die walls and communicating with the interior of said die between the zone where said skin is formed and the exit end of said die, and means for supplying to said ports a non-liquid lubricating material.

15. In the method of continuously casting metal which consists of continuously feeding molten metal to one end of a hollow chilled die at a velocity permitting said die to congeal at least the outer surface of the metal within the die, and continuously removing the chilled metal at the exit end of the die, the step comprising continuously introducing a non-liquid lubricating material between the congealed surface of the metal and the wall of the die from the zone where said congealed surface normally forms to the exit end of the die.

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