

Aug. 25, 1942.

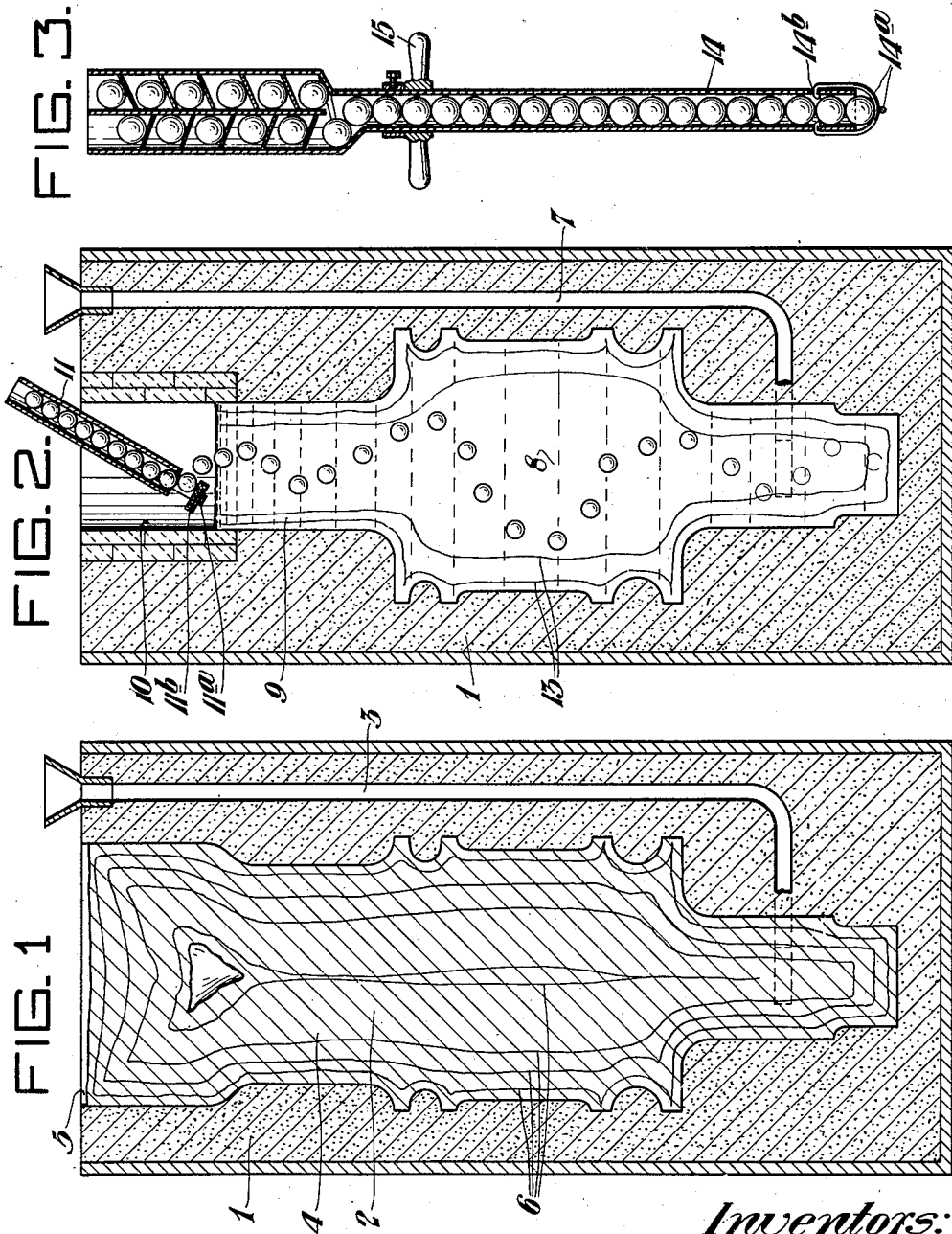
C. B. FRANCIS ET AL

2,294,170

METAL CASTING

Filed April 9, 1941

3 Sheets-Sheet 1



Inventors:
CHARLES B. FRANCIS,
ROY H. NODERER and
RALPH B. PORTER,
by: *John E. Jackson*
their Attorney.

Aug. 25, 1942.

C. B. FRANCIS ET AL

2,294,170

METAL CASTING

Filed April 9, 1941

3 Sheets-Sheet 2

FIG. 4.

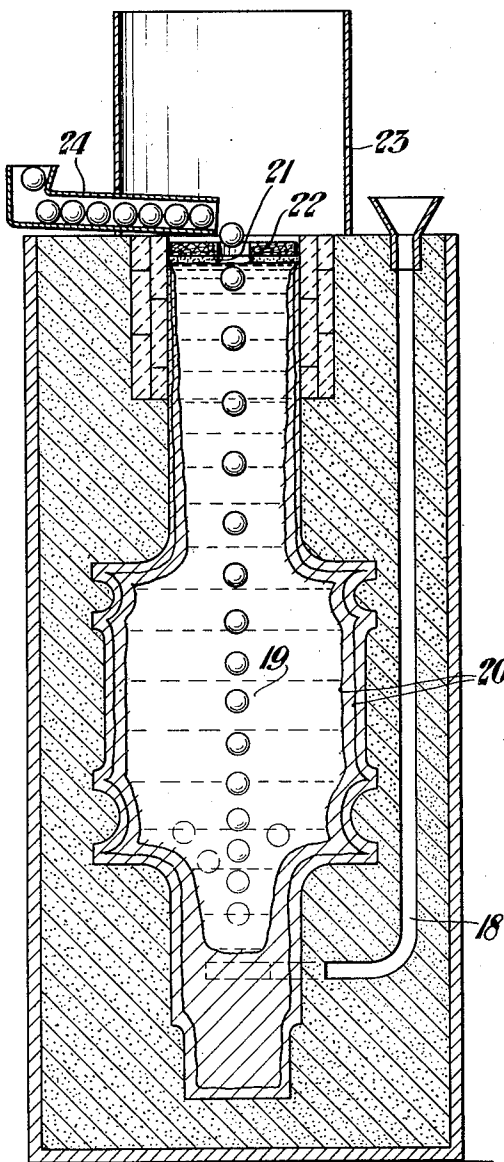
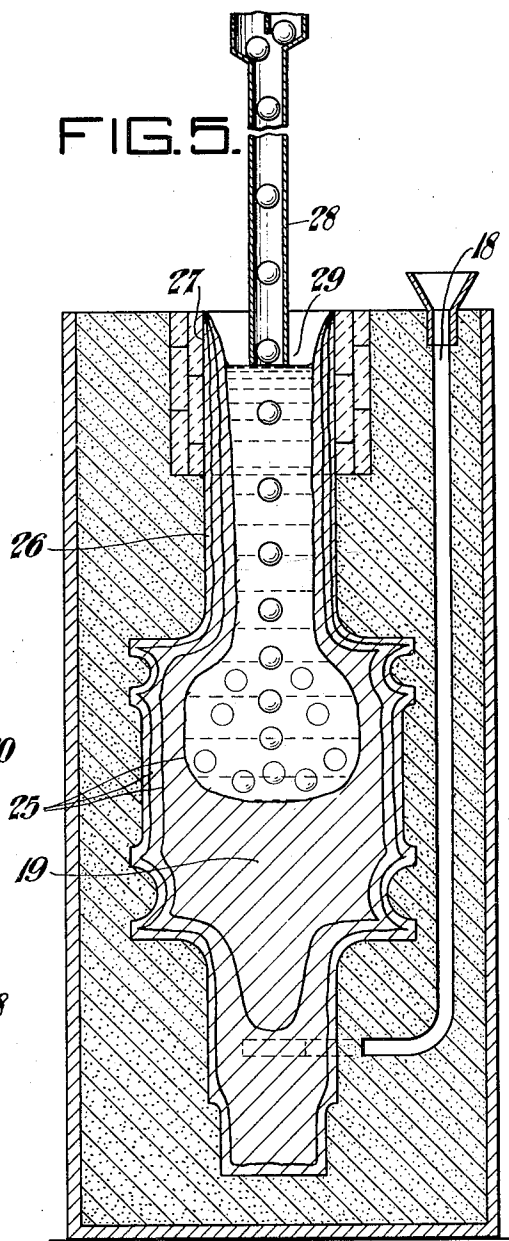


FIG. 5.



Inventors:

CHARLES B. FRANCIS,
ROY H. NODERER and
RALPH B. PORTER,

by *John E. Jackson*
their Attorney.

Aug. 25, 1942.

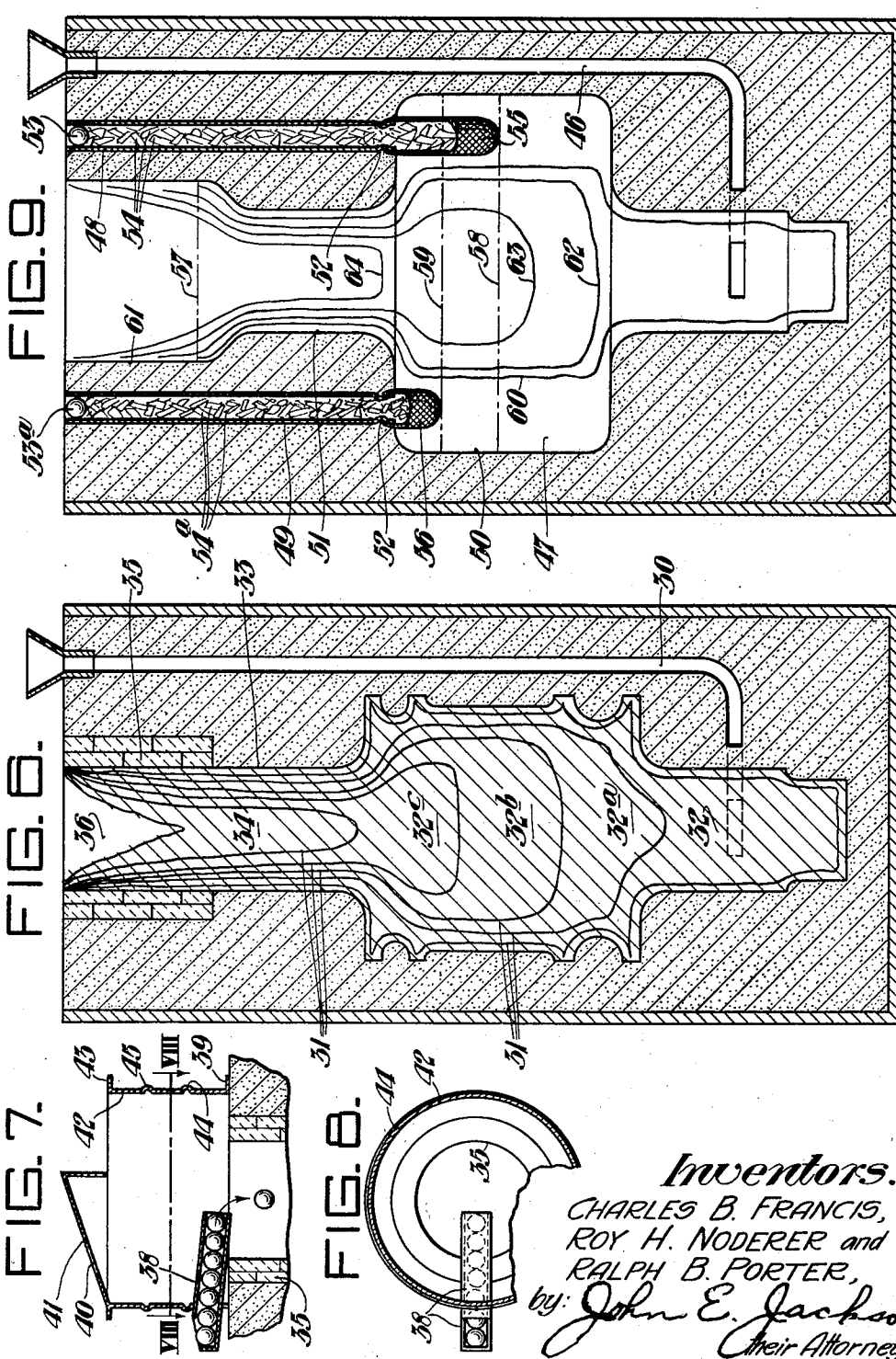
C. B. FRANCIS ET AL

2,294,170

METAL CASTING

Filed April 9, 1941

3 Sheets-Sheet 3



UNITED STATES PATENT OFFICE

2,294,170

METAL CASTING

Charles B. Francis, Pittsburgh, and Roy H. Noderer and Ralph B. Porter, Johnstown, Pa.

Application April 9, 1941, Serial No. 387,742

17 Claims. (Cl. 22—215)

This invention relates to an improved method and apparatus for the casting of metal articles of large cross section, and particularly to the casting of such articles made of either iron or steel, which are the materials most widely used for such purposes and are also the most difficult to cast properly. Therefore, while the process of our invention may be applied in the casting of any metal used in the production of articles of large size, we confine the description of this disclosure to casting of iron and steel, and to further simplify the description of the practice and the explanation of the principles of our invention, we restrict the following specification to one example of its application; namely, a large steel roll such as is used in mills for the rolling of steel. Any roll of this type has a varying cross section, and such rolls frequently require 20,000 to 100,000 pounds of molten metal, both of which factors make the casting operations difficult and contribute to the many defects found in such castings. Frequently these defects are a cause for the rejection of the casting and are revealed only after much work has been done upon it.

Besides the defects attributable to improper melting and molding practices, large castings of the type in question are subject to others considered unavoidable by the practices of the prior art. These unavoidable defects result from segregation and changes in volume during solidification of the metal and are known as center zone porosity, pipe, cokey texture, dendritic and columnar structures, shrinkage cavities, shrinkage draws and internal hot tears. All weaken the casting, and many are accepted as sufficient reason for rejection of the casting by the purchaser.

A principal object of our invention is to eliminate these defects entirely, while secondary objects are to improve the finished casting and to cheapen the process of manufacture as compared with the cost of manufacture by the practices of the prior art, by decreasing the amount of molten metal required to make a given casting and by reducing the number of heat treatments to refine the structure and the amount of machining necessary to be done after the casting has been formed. The following examples suffice to show how and to what extent we have succeeded in the accomplishment of these objects:

Referring to the drawings, Figure 1 represents a vertical sectional drawing of a large grooved roll as it stands in the mold after casting and solidifying slowly in accordance with the practices of the prior art;

Figure 2 is similar to Figure 1 but shows apparatus embodying the present invention;

Figure 3 is a detail of the apparatus;

Figures 4 and 5 are modifications of Figure 2;

Figure 6 shows the progress of the solidification of the molten casting;

Figure 7 is a vertical sectional view of a sinkhead and associated apparatus used in carrying out certain phases of the invention;

Figure 8 is a cross section taken from the line VIII—VIII in Figure 7; and

Figure 9 is a modification of Figures 2, 4 and 5.

In these drawings are found the numeral 1 representing the mold, 2 the casting and 3 the gate through which the molten metal was introduced into the mold. By this practice the upper neck 4 of the roll must be cast much larger than required by the finished casting, so that the metal in it will be the last to solidify and will flow downward from the sinkhead 5 until the metal in the roll proper has solidified. In such a mold, solidification of the molten metal progresses very slowly in directions at right angles to the inner surfaces of the mold, and the progress of solidification may be represented by isothermal lines 6. Following these isothermal lines to the center line of the casting, it is observed that large cavities appear in the sinkhead 5, which represents metal that has flowed downward to compensate for the liquid-to-solid contraction of the metal below. Usually, the capacity of this sinkhead is approximately $\frac{1}{3}$ of the volume of the mold below it, because the metal freezes from the top of the sinkhead as well as from the sides.

These statements refer to the practices of the prior art. In the complete application of our process we employ a mold with a sinkhead having a smaller diameter than the sinkheads of the molds that are used in the practices of the prior art, the sinkheads of our molds having a facing of refractory brick as illustrated in the drawings, Figures 2, 4, 5 and 6; and we preheat the interior of this sinkhead to a high temperature just prior to casting, by a method and apparatus described in a copending application bearing Serial No. 385,172 and filed March 25, 1941.

Below this pipe cavity other cavities of small size are formed about the periphery of the casting, starting $1\frac{1}{4}$ to 2 inches under the outer surface and extending downward. These small cavities are formed as a result of selective freezing and segregation, giving rise to pockets of low melting constituents that flow downward as the metal below solidifies, and are liable to be exposed in machining this portion of the casting to

size, and are sure to be encountered if the rim of metal removed by machining is more than 2 inches thick.

To prevent the formation of these defects is an immediate object of our invention, an object we accomplish by controlling both the direction and the rate of solidification, causing the metal to commence solidifying at the bottom of the casting and to continue rapidly upward.

Figure 2 represents the design of mold in vertical cross section we employ to produce the same roll as that shown in Figure 1, in which the part designated by the numeral 7 is the gate to the mold and the part designated by the numeral 8 is the casting itself. It will be noted, especially, that we have greatly reduced the diameter of the neck 9, and the size of the sinkhead 10, as compared with the corresponding parts 4 and 5 of Figure 1 representing a mold for the same casting made by the practices of the prior art. By drawing in isothermal lines 13, marking the advance of solidification as it occurs naturally, it can be shown that the neck 9 would completely be solid long before the metal in the large body below has solidified, a condition that would result in the formation of a large pipe located in the upper portion of the body and across the bottom of the neck. But we prevent the formation of such a pipe by causing the metal to solidify quickly at the bottom of the casting and progress rapidly upward, by adding at proper intervals a correct quantity of specially treated iron or steel balls to the liquid steel after it has been poured into the mold, or by inserting a bar of iron or steel before or after casting to initiate solidification at the bottom of the casting, and subsequently adding steel in the form of small bodies, such as balls or cubes. Instead of balls, we may use small bodies of iron or steel in various forms such as cubes, short cylinders or pieces of plates of irregular shape. Both the size or weight of each body and its shape are important because they affect the rate of fall and also the rate of heat transfer. For example, spheroidal bodies will fall faster through the liquid and heat up more slowly than flat bodies of the same weight.

In order that we may thus control the rate and direction of solidification in tall castings having a height of 100 inches or more, we proceed as follows:

First, we introduce the liquid metal through the gate 7 until its top surface rises into the lower part of the sinkhead 10, which is preferably preheated.

Next, by means of a suitable apparatus such as that shown in cross section in Figures 2 and 3, we initiate the first stage of solidification by introducing a predetermined weight of specially treated bodies of steel or iron, preferably in the form of balls. With the apparatus of Figure 3, the container, filled with the required number of balls, is lowered until its tip 14, which is capped by an alloy having a low melting point, such as aluminum, just touches the center of the liquid metal surface, the heat from which melts the cap almost instantly, so that the bottom tip gives way, permitting the balls to descend into the molten metal. Generally the surface of the metal is covered by foreign material gathered as the swirling metal rose in the mold, and to prevent this dirt from being carried downward by the rushing of balls, it is brushed aside from the center with a small bar of iron or a pole of charred wood just before the tip of the container is brought into contact with the molten metal.

Another type of feeding device we have found even more satisfactory than that of Figure 3, especially for adding balls of small size, is the open tube 11 of Figure 2. The lower end of this tube is provided with steel straps 11^a which support a water soaked wood block 11^b, such a distance below the end of the tube that the space between the upper surface of the block and the tube is slightly greater than the diameter of the balls to be introduced into the swirling metal. By properly supporting this tube at an angle, as shown in the drawings, balls fed in at the upper end first strike the block of wood then tumble gently into the molten metal at various points, thus preventing the balls from descending in clusters as are likely to be formed when the balls are introduced by any other method. Both of these operations are carried out in a few seconds of time, so that the balls drop into the molten metal while it is still swirling.

The effect of thus introducing a suitable number of balls of proper size is explained as follows:

If the balls should be introduced after the swirl ceases, they would descend in a continuous column and at a relatively rapid rate, so that a number would land in the lower neck of the roll before they are melted, and these may not melt completely because of insufficient heat as a result of the combined heat absorption of the balls and the mold. We desire particularly that all of the balls in this first addition should melt entirely, unless the balls are made of steel having the same composition as that of the casting, in which case it is immaterial whether the balls melt or not, as they become bonded with the steel of the casting. When the balls are added in the swirl, as we aim to do always by the method of our invention, the balls in the column are separated and thrown off center by centrifugal force, so that they descend in a spiral path as represented by the line 12 in the drawing of Figure 2. Thus separated from others in the column, each ball is at first drawn downward through the liquid steel by the force of gravity, the liquid steel having a density of about 7.25 g. per c. c. and the cold solid balls a density of about 7.78 g. per c. c.

The rates or speeds of descent of the balls, as well as the direction of descent, play a vital part in the process of our invention, and are described as follows:

Each ball, the first one from rest, enters the liquid under the full force of gravity, which is equal to $7.78 Vg$ dynes, where V represents the volume of the ball in cubic centimeters and g the force of gravity. As soon as the ball enters the liquid steel this force is partly counteracted by the buoyant force of the liquid, which is equal to $7.25 Vg$ dynes, so that the effective downward force is only $0.53 Vg$ dynes, or 0.53 g., and the acceleration caused by gravity is reduced from about 32 feet per second to slightly less than 2.18

$$\left(32 \frac{7.78 - 7.25}{7.78}\right)$$

feet per second, per second, making the maximum space through which the ball could move in the first second about 1.09 feet. In the liquid steel the acceleration is much less and the distance the ball travels the first second is also much less than 1.09 feet per second, because the viscosity of the liquid metal creates a force of displacement that further opposes the full force of gravity, and since this second opposing force increases with the viscosity of the liquid and the

square of the speed or velocity of the ball, the fall of the latter becomes constant, that is, the speed of the ball attains a certain constant or terminal velocity within 2 seconds, the exact terminal velocity depending upon the temperature and viscosity of the liquid steel and the size of the ball, as well as the speed with which it enters the liquid.

By experiment we have found that a ball $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter, starting from rest at the surface of the liquid steel, reaches a terminal velocity of about 6 inches per second within a period of about 1.2 seconds and a space of 5 to 8 inches. The distances are increased slightly if the balls are propelled by a force at a low velocity as the balls enter the surface of the liquid steel, but if they enter at high velocity, as when dropped through the air for a distance of 20 or 30 inches, the opposing force of displacement is such that they are forced along a path forming a loop at a depth of 10 to 15 inches, which may propel them against the mold wall of the neck of the roll where they may adhere permanently. This eventuality is avoided by introducing the balls from a tube-like container, as shown in Figures 2 and 3. By this means we are assured that all the balls will pass below the level of the upper roll neck during the first 2 or 3 seconds of their descent through the liquid, a result that is important for another reason also. Other means may be employed to obtain a like result.

After a ball has traveled at terminal velocity for about 2 seconds, or a total distance of 20 to 30 inches in a total time of 3 seconds, its descent becomes constantly retarded so that the velocity of a 1-inch ball becomes almost zero 8 to 12 seconds later, because, as soon as the cold ball contacts liquid steel, it solidifies up to $2\frac{1}{2}$ times its weight or volume of the liquid upon its surface, thus increasing its size and its temperature, so that the effective downward force of gravity is decreased to about $0.23 Vg$ and the opposing force of displacement is increased, not only because of the increased size of the ball, but also because the metal at the bottom of the mold is losing heat and becoming more viscous. This shell of newly solidified metal ordinarily begins to form as soon as contact is made with the liquid steel, but, to permit the ball to drop to a greater depth the first second, we delay the formation of the shell by special treatment of the balls as described later. Thus we assure that the balls drop rapidly through the neck, then more and more slowly until they come to rest at points near the bottom of the mold, but out of contact with its wall or bottom. Here, if the balls are not too large or too numerous, they absorb heat from the liquid steel until both the shell and the ball melt and become mixed with the rest of the metal.

The size of the balls is important. A 3-inch ball we have found may reach the bottom of any mold and cause solidification of so much metal about it that it will not melt. We, therefore, have selected 2 inches as a medium or standard size of the ball that may be used for any casting, and vary the size from $\frac{1}{2}$ to 3 inches according to the size of casting, the smaller sizes being used in the smaller castings and the smallest size for first additions in all castings. For short or low molds, say less than 72 inches tall, balls smaller than 1 inch in diameter are desirable for the first addition, and small, flat thin bodies may be more desirable than balls for shorter castings, as such bodies heat faster and fall more slowly than balls since they fall with their flat

surfaces lying horizontally and the resistance of their fall is proportional to the horizontal cross sectional area.

The time of holding after pouring before adding the balls is also a factor affecting the maximum size of ball that may be used. For example, if the casting after pouring can be permitted to stand 15 to 20 minutes to permit the formation of a solid shell 1 to 2 inches thick before any balls are added, larger balls may be used for the first additions than when they are added in the swirl.

Concerning the weight, or number of balls of a given size, to be added to any casting or any part thereof, this quantity may be calculated from the following equation:

$$x(ut \ 0.1451) + (0.27 \ st) su + (0.145 \times at) fw = (dt \times 0.15 + 65) w$$

where x = weight of the balls; ut , the degrees rise in temperature required to raise the temperature of the balls to the solidus temperature of the liquid steel; 0.1451, the average specific heat of the balls over this temperature range; 0.27, the specific heat of the sand in the mold; st , the average temperature rise of the sand; su , the weight of the sand; 0.145, the specific heat of the flask; at , the average rise in temperature of the flask; fw , the weight of the flask; dt , the temperature drop of the liquid steel in cooling to the liquidus; 0.15, the specific heat of the liquid steel; 65, the heat of solidification of the liquid steel; and w , the weight of the steel in the lower part of the mold it is desired to solidify.

In practice we have found it desirable to cool the liquid steel only to within 5 or 10° of the liquidus point, as this cooling permits the balls to melt and also brings about rapid solidification of the liquid steel through the heat absorbing capacity of the mold, which may vary greatly according to the construction of the mold. Now, good casting practice requires that the steel be poured at as low a temperature as possible to avoid fusion of the sand to the casting, the highest permissible being approximately 120° F. above its liquidus, and we allow 40° F. drop in this temperature for cooling effect in pouring, making the temperature drop to be effected by the balls 80° F. or about 50° C. As the specific heat of the liquid steel is 0.15 cal. per gram, the heat to be absorbed is $70 \times 0.15 = 10.5$ cal. per gram. Now the heat absorbed by 1 g. of the balls may be calculated from the formula,

$$bh = 0.145 \times tl + 65 + 10 \times .15$$

in which bh is the heat absorbing capacity in calories of 1 g. of the balls; 0.145 the average specific heat of steel; tl the temperature rise in degrees centigrade to bring the temperature of the balls to the solidus; 65 the heat of fusion of the balls; 10 the temperature in degrees centigrade above the liquidus; and 0.15 the specific heat of liquid steel.

For steels containing about 1.5% carbon, the heat absorbing capacity of the balls is found to be about 241 cal. per gram, or 23 times the heat to be absorbed from the liquid steel. With this factor established, we find the maximum weight of balls to be added from the weight of metal in the portion of the mold to be cooled, 1 inch being subtracted from the height and the diameter, that is, $\frac{1}{2}$ inch from the radii, to allow for the metal solidified against the wall of the mold by the time the pouring is completed. In practice it is found that the thickness of shell formed during the pouring varies considerably depend-

ing upon the composition of the steel, the pouring temperatures, the rate of pouring and a number of lesser factors. Incidentally, the volume of the balls added in accordance with this method is approximately the same as the liquid-to-solid contraction of the metal in this part of the mold, which we find by multiplying the volume, less the volume of a shell 1 inch thick, by the factor 4.4. Both methods give the maximum number of balls to be added, and we generally use 75% of this number, increasing the number, if the pouring temperature is high. Other methods of quickly finding the proper number of balls to add may also be used. For example, we have found that 1 ball 1 inch in diameter will lower the temperature sufficiently of 20 cubic inches of liquid metal in large castings or 40 cubic inches of metal in small castings, the exact number depending upon the heat absorbing capacity of the mold and the flask.

One apparatus we have found suitable for introducing the balls into plain rolls at this stage of the process is shown filled with balls in Figure 3. It may be made of wood or steel, and consists essentially of a tube 14, provided with a suitable handle 15, and a special tip 14^a, which is made of a low melting alloy in the form of wires so that the heat will melt it and release the balls as soon as it approaches or makes contact with the surface of the molten metal. This tip should be of a substance that will not affect the steel, and the tip we have found most satisfactory is made of aluminum wire, which may be laced across the opening through holes in the wall, as shown at 14^a, so that the bottom ball projects somewhat below the end of the tube itself. To increase the holding capacity of the tube without increasing its length, so that it will not be top heavy, a top portion enclosing a spiral inclined plane is used, because the balls jam or bridge across the opening of a hopper or funnel-shaped top. For this reason we prefer a straight tube, and to lower it by machine, or with a small jib crane. In general, however, we prefer to introduce the balls by the simple method described below.

In the casting of certain rolls, for example, those with small necks and deep grooves, we have found it advantageous to insert a bar of metal of the same composition as the casting, either before or immediately after casting and covering to initiate the solidification at the bottom, instead of adding balls in the swirl. For this purpose we have found it feasible to use the gates which are of the same length as the castings with a much smaller bar attached by welding to one end of the gate. In carrying out the process, the gate, thoroughly cleaned, is suspended or lowered coincident with the long axis of the roll, and supported so that its upper end just protrudes from the liquid steel. After 5 to 20 minutes, according to the diameter of the insert bar, the lower end of the insert bar has melted. Then we lower the upper portion until the attached bar is totally immersed, by which operation we are assured that the crystallized column formed by and about the insert bar is lowered through the sinkhead and neck into the lower part of the body of the roll, where it accelerates the cooling of the metal by abstracting heat and forces the hotter metal upward into the neck and sinkhead, which we desire to keep fluid until all the metal in the body has solidified. Subsequently, we make additions of balls as when no insert bar is used initially. The insert will vary in di-

ameter in proportion to the size of casting up to a maximum insert diameter of 3 inches. For illustration, an 18-inch casting will require an insert of 1 inch diameter. Three inches is the maximum diameter of bar which will melt in the cast molten metal within the 20-minute period; therefore, the 3-inch bar is the maximum sized bar used. Also, castings smaller than 18 inches will require a bar of proportionately less than 1-inch diameter.

Preparations to control the solidification in stages subsequent to the first must be made immediately following the first addition of balls. Consequently, as soon as the first lot of balls have been introduced into the swirling metal, the ladle is moved over the sinkhead, which is then filled to the top with liquid steel. Any dirt on the surface of the steel is raked off, and the metal is covered by an exothermic insulating mixture of nonmetallic substances such as that sold under the trade name of "Lunkerite" to prevent a crust forming on the surface. This mixture consists of powdered aluminum, alumina, fluorspar, and calcium carbide, and reacts with both iron oxide and the oxygen of the air to produce heat and form at first a fluid slag which later becomes very viscous or a brittle solid. In casting rolls shorter than 100 inches we may not attempt to add balls until the mold is full, when we may add the first lot of balls just before the top covering is applied except about the edges of the sinkheads which should be covered as soon as possible to prevent the formation of a thick crust of metal.

With this mixture the method we have found most satisfactory for application in the addition of the steel balls to both large and small castings is illustrated by Figure 4. By this method we proceed as follows:

As soon as the sinkhead has been filled with molten steel and the dirt skimmed off and the first lot of balls added, if these have not been previously added in the swirl, we add the exothermic covering mixture to a depth of about ½ inch, and place upon this covering a charred wood block, which is in turn immediately covered with finely crushed bituminous coal to prevent the block from burning.

This block is 2 to 3 inches thick, and is 1 to 2 inches smaller in other dimensions than the section of the sinkhead. It contains a hole at its center slightly larger than the largest ball to be added to the liquid steel, and as soon as, or before, the block is placed upon the covering, this hole is filled with the exothermic covering mixture and covered with a piece of board, so that the coal poured upon the block cannot get into the hole or become mixed with the exothermic covering mixture. By brushing aside the coal, removing the piece of board, entry to the molten steel beneath the exothermic covering may be had at any time by pushing a rod through the mixture filling the hole in the block.

After a period of 5 to 10 minutes has elapsed, we proceed with the second step of our process, which is represented by Figure 4. By this time solidification of the metal at the bottom of the mold has progressed inward and upward, as indicated by the isothermal lines 20, and the casting is in a condition to receive more balls. Before these balls are added, a circular metal shield 23 may be placed about the top of the mold as a safety precaution against splashes of liquid slag or metal, but we have rarely found it necessary to use a shield. To add the balls, a hole is

punched through the insulating cover at the center of the wood block, which is over the center of the sinkhead, and the additional balls required to initiate solidification to the level desired are fed slowly through a tube or trough 24, to drop through the center hole in the wood block. Since these balls descend in a straight line coincident with the center line of the casting, they are added slowly, the 1-inch balls at the rate of 1 per second and the 2-inch balls at the rate of 1 every 2 seconds. To assure that all, or the greater portion, of these balls will be melted, a number sufficient to initiate solidification only in the lower half of the body are added at this stage, and the number required to obtain this result is calculated as explained above for those added while the metal is swirling. Usually the weight of balls added in this second step is 2 or 3 times the weight of those added in the first step, but seldom more than $\frac{1}{4}$ of the total to be added.

As soon as these balls have been added, the shield is set aside, the hole in the center of the wood block is filled with the exothermic covering mixture, the piece of board is placed over the hole and the block is covered with coal as before.

After another interval of 10 to 20 minutes, the hole in the wood block is opened, and the level to which solidification has progressed is determined by inserting a steel rod through the hole, permitting it to descend through the liquid steel of its own weight until it comes to rest, then withdrawing it quickly and measuring the length upon which metal has solidified upon its surface.

The final addition of balls to initiate solidification of the metal in the upper half of the body is made in one or more lots 1 to 3 hours after pouring, the exact time of adding each lot, as well as the number of lots, being determined by the size of the casting and the diameter of the neck, for it is evident the addition or additions must be made before solidification in the neck 26 of Figure 5 has progressed to within about 6 inches of the center. To find the maximum time interval after casting, we assume that solidification has advanced inward from the wall of the neck a distance of 1 inch in a time of 1 minute after pouring and that thereafter solidification advances at a rate measured in inches which varies inversely as the square of the time measured in minutes. At this rate, it requires about 1 hour for a shell $1\frac{3}{4}$ inches thick to solidify about the walls of the mold, but solidification in the neck may be faster and the metal in this part of the mold may become so viscous that any balls added will not pass through it. The exact time when the addition of balls should cease can be judged by the speed with which the gage rod descends and the amount of metal that solidifies upon it during the 3 seconds of its exposure to the liquid steel. Thus, the insertion of a gage rod into the liquid steel in the mold becomes a means by which we control the solidification and also a means of ascertaining when the addition of balls should cease.

The number of balls to add at this stage may be found by calculation from the volume of metal enclosed by the third isotherm (see 25 of Figure 5), and are $\frac{1}{2}$ to $\frac{2}{3}$ of the number added in the second step. To introduce these balls, one of two procedures may be used. If the metal in the surface of the sinkhead has not sunk perceptibly, the balls may be introduced through the hole in the wood block and the insulating

covering as described above for the second step of the process. If the metal has sunk to a depth in the sinkhead, we have found it convenient to brush the coal covering the wood block aside, which soon permits it to burn through at the center, and then to introduce the balls with the apparatus of Figure 3, as described for the first step of the process. After this final addition of balls, the metal remaining molten in the sinkhead is again covered by adding more of the exothermic or thermite mixture and another charred block of wood, as previously described herein.

By proceeding in this manner, we bring about rapid solidification of the casting from the bottom upward, leaving, after the final addition of balls, only the metal in the neck to solidify. The progress of the solidification is illustrated by the isotherms 31 of Figure 6, in which 30 represents the grating to the mold; 32 the portion solidified by the first addition of balls; 32^a the portion solidified by the second addition of balls; 32^b the portion solidified by the third addition; and 32^c the portion solidified by the fourth addition, leaving only the metal 34 in the neck 33 in the liquid state to be fed by the liquid steel in the preheated sinkhead 35, which metal is protected by the covering of the thermite mixture and charred wood. The sunken top portion 36 we fill with the hot charcoal and coke formed up to the final operation, and cover this with a heavy layer of crushed bituminous coal to prevent rapid heat loss through the top of the sinkhead.

The construction of the shield used for adding the balls in the second step, after the mold has been filled with liquid steel, is indicated by the drawings of Figure 7, showing the shield in vertical cross section, and of Figure 8, showing a cross section of the bottom part of the shield and of the chute through which the balls are added. In these drawings the part 37 represents the sinkhead of the mold; 38 the chute for adding the balls, and the other numerals the construction of the shield. The shield is made of 18 to 20 gage sheet iron, with a rim 39 at the bottom, a similar rim 43 at the top, and two or more corrugations, 43 and 44, to strengthen it. This shield is preferably provided with a top portion 41, provided with a peep hole 40.

The composition and preparation of the balls require explanation. With respect to composition, the balls may be made from any grade of steel desired without markedly affecting the results obtained with regard to solidification and the elimination of columnar and dendritic structures and other causes of center zone weakness. To accomplish these objects, we prefer the balls to be made of steel having the same composition as the rest of the casting, because there is no danger that these balls will produce hard or soft spots in the roll if they fail to melt entirely. However, the balls may be of any composition desired, and it is thus possible to alter the composition of the steel in the interior portion of a casting to improve its toughness, or strength and ductility. Thus, it is possible to produce a kind of composite casting having an exterior of one type of metal and an interior portion of a slightly different type. For some castings we may use small balls or cubes of pig iron. This material, being high in carbon, has a low melting point and the excess carbon soon diffuses after the balls melt. As a substitute for the first balls added, when the metal is swirling, we may use steel cut-

tings from the lathes, or other discarded parts of castings, a procedure that simplifies the problem of providing balls having the same composition as the castings.

The preparation of the balls is important. To avoid starting gas forming reactions within the steel of a casting and assure perfect bonding between the cast metal and any balls that may fail to be completely melted, the balls must be free from scale, rust or iron oxide in any form as well as from any other foreign matter, such as dust, sand, clay, or other dirt. To obtain these qualities in the balls and also provide a method whereby the balls may be prepared at any time convenient and used at any subsequent date, we treat them as follows:

To avoid absorption of hydrogen and supply heat to the solution, we first heat the balls to a dull red color, then transfer them to a basket made of acidproof metal and immerse them in a 6% to 10% solution of sulphuric acid until all scale and oxide are removed. We then rinse them in a 1% solution of hydrochloric acid to remove the ferrous sulphate, dip them in a 5% solution of sodium cyanide, and permit them to dry. As soon as they are dry the balls are immersed in a special oil mixture, which is capable of reacting with the sodium cyanide and forming a film that will protect them from rusting for indefinite periods of time. The oil mixture is composed of 3 parts of a petroleum oil of a grade known as slushing oil, and 1 part of a mixture composed of about 60 parts soy bean oil or linseed oil, 20 parts slushing oil, 10 parts crude castor oil and 10 parts crude turpentine. The turpentine is added to the castor oil to thin it. This mixture is added to the soy bean or linseed oil, and the slushing oil is then added to the mixture.

Figure 9 illustrates a special modification of the process of our invention, adapting it to the production of rolls and similar articles having an extremely wide body section. In this drawing, which is a vertical section through the center of the casting as it stands in the mold, 46 represents the gate through which the liquid metal is introduced into the mold and 47 the casting itself. In such a casting the extremely wide body makes it difficult to build a mold that will cause upward solidification of the liquid metal to progress uniformly across the section by the simpler procedure described above. Failure to accomplish this object leaves a zone of unsoundness in the casting that occurs as an annular ring a few inches inward from the outer surface of the body. We overcome this difficulty and produce a sound casting by modifying the construction of the mold and the method of introducing the bodies of solid metal as follows:

In constructing the mold we build into it one or more steel tubes, 48 and 49, at a point or points suitably located between the outer circumference 50 of the body of the roll and of the neck 51. Each of these tubes has a straight wall except at the bottom near the outlet to the mold, where the wall of the tube is indented at point 52 to hold a neatly fitting ball 53, which descends with the smaller particles of steel 54, and performs the function of a shut-off valve to the liquid metal, as described later. The small particles of solid metal 54 are supported in the tube 48 or 49, by net-like pockets 55 or 56, made of metal wire having a melting point much below that of steel, preferably aluminum. Usually the longer net 55 is made of aluminum wire and the shorter net 56

of copper wire. The tubes are inserted when the mold is prepared and filled with the small particles of steel after the mold has been set up for casting.

With the mold thus prepared and mounted, the procedure in casting is as follows:

First, we will fill the tubes 48 and 49 with the cold steel to be added to the liquid steel to initiate the solidification of the molten steel in the body of the roll. This steel is in the form of small bodies, which have been pickled to free them of scale and treated with sodium cyanide and oil to prevent them from rusting, as described for the treatment of the cold steel in the form of balls. However, the cold steel we introduce into the liquid steel, in the present instance, must be in the form of bodies smaller than 1 inch, and may consist of coarse chips obtained in the rough machining of the castings or of pieces broken in any manner to pass a 1/2 inch round hole screen. As the steels used for castings are generally high in carbon and alloys that give a very hard metal by quenching, we may obtain them by forging the gate runners into flats less than 1/2 inch thick, heating the flattened plates to about 1500° F., hardening them by cooling rapidly or slowly as required and quenching them in water and breaking them in a crushing machine or under a steam hammer. After filling the tubes 48 and 49 with these small bodies of steel, we place at the top of each tube a large steel ball, 53 and 53^a, that neatly fits the inside of each of the tubes 48 and 49, which may vary from 2 inches to 3 1/2 inches in diameter, according to the quantity of steel we desire to add at this point. The total weight of steel to be added is determined by the size of the roll body, and the extent to which it is desired to initiate the solidification, and is calculated as already described for the addition of the balls. With the tubes thus filled with the pieces of cold steel to be added, the introduction of liquid metal through the gate may be started at any time convenient.

The molten metal is introduced through the gate 46 in the usual manner until the liquid rises through the neck to a level 57, 6 to 10 inches above the top edge of the neck. During this operation the tubes 48, 49 are automatically emptied of the charges of small particles of steel they contain, as follows:

When the top surface of the liquid metal in the mold rises to the level 58, it contacts the bottom of the net 55 and immediately melts the aluminum wire, which ruptures and permits the load of small bodies of steel it supports to flow into the liquid steel. Since this metal is swirling at a fast rate, the particles of steel are scattered and carried about the circumference of the roll, melting and cooling the liquid metal. The large ball 53 descends with the contents of the tube, but is stopped by the indentation 52. Then as the liquid continues to rise to level 59, it contacts the aluminum net of the second tube, which melts and permits the contents 54^a of the tube 49 to descend into the liquid steel 2 or 3 inches below the top surface of this portion of the mold. The large ball 53^a descends with the contents of the tube and is stopped by the indentation 52, as in the case of tube 48.

As the metal fills the mold and starts to rise in tubes 48 and 49, it contacts these large balls and is immediately chilled, or solidified, so that further upward flow through these openings is stopped at these points.

The metal thus introduced through these tubes is kept near the circumference by the centrifugal force of the swirl, and by properly proportioning the cold metal added in this manner to the size of the body, we cause such a chilling effect that this metal is quickly solidified against the mold wall by the heat it abstracts, and adjacent metal becomes somewhat viscous. Thus, by the time the surface of the liquid metal in the mold reaches a level 57, solidification is rapidly progressing inward towards the isothermal lines 60. To make sure that solidification has progressed inward to the loci of points indicated by this line, we cover the surface of the metal in the sinkhead with the exothermic covering mixture previously described and stop pouring through the gate 46. After 5 to 10 minutes, we then introduce a quantity of cold steel in the form of bodies, such as balls, through the surface 57, sufficient to cause solidification to progress upward to the isothermal line 62, then fill the sinkhead with molten metal introduced through its top. The top surface of the metal is then covered as described above for the treatment of rolls with bodies of smaller diameter in proportion to the neck, and the solidification is made to progress upward in steps indicated by the isothermal lines 63 and 64, by the addition at intervals of cold steel in the form of balls, as described previously for the control of the solidification of the steel in rolls having bodies of smaller diameters.

Having thus made a complete disclosure of our invention by exposition and example, we desire to have it understood that various modifications may be made in its application to different metals and castings of iron or steel without exceeding the scope of our invention as defined by the following claims.

We claim:

1. The process of producing castings of iron and steel which involves the steps of preparing a mold of the desired form and dimensions, introducing the molten metal in this mold through a gate at the bottom until the mold is filled with the liquid metal, covering the surface of the liquid metal with a mixture of compounds that react exothermally with iron oxide and oxygen, and thereafter adding at intervals portions of metal, in the form of small scale-free bodies and of a composition similar to that of the casting, to cause solidification of the liquid metal of the casting to progress upward at a faster rate than solidification advances in directions normal to the inner surfaces of the mold.

2. The process of casting rolls of iron and steel, and of causing the liquid metal of which they are made to solidify upwards at a rate faster than the solidification in directions normal to the inner surfaces of the mold, by the addition at intervals of portions of solid metal in the form of small bodies, which process involves the steps of freeing the surfaces of the solid bodies of oxide and coating them to prevent them from rusting, forming a mold of the desired shape and dimensions with a suitable sinkhead, admitting the molten metal through a gate at the bottom of the mold, adding portions of the solid metal to the liquid metal as it rises in the mold, filling the sinkhead with the molten metal, covering the surface of the top of the liquid metal with an insulating mixture of compounds that react exothermally with iron oxides and oxygen, placing upon the exothermic mixture, a dry charred wooden block with a hole in the center, and sub-

sequently adding at intervals portions of the treated solid bodies to cause solidification of the liquid metal to advance upward at a rate so that the body of the roll is practically solid before the metal in the upper neck of smaller diameter has completely solidified.

3. The process of casting rolls of iron and steel, and of causing the liquid metal of which they are made to solidify upwards at a rate faster than the solidification in directions normal to the inner surfaces of the mold, by the addition at intervals of portions of solid metal in the form of small bodies, which process involves the steps of freeing the surfaces of the solid bodies from oxide and coating them to prevent them from rusting, forming a mold of the desired shape and dimensions with a suitable sinkhead, admitting the molten metal through a gate at the bottom of the mold, adding portions of the solid metal to the liquid metal as it rises in the mold, filling the sinkhead with the molten metal, covering the surface of the top of the liquid metal with an insulating mixture of compounds that react exothermally with iron oxides and oxygen, placing upon the exothermic mixture a dry charred wooden block with a hole in the center, and subsequently adding at intervals portions of the treated solid bodies to cause solidification of the liquid metal to advance upward at a rate so that the body of the roll is practically solid before the metal in the upper neck of smaller diameter has completely solidified, said solid metal being of a different chemical composition from that of the liquid metal that is cast.

4. The process of casting rolls of iron and steel, and of causing the liquid metal of which they are made to solidify upwards at a rate faster than the solidification in directions normal to the inner surfaces of the mold, by mounting a solid bar of metal approximately the same composition as the liquid metal and by the addition at intervals of portions of solid metal in the form of small bodies, which process involves the steps of freeing the surfaces of the solid bodies from oxide and coating them to prevent them from rusting, forming a mold of the desired shape and dimensions with a suitable sinkhead, mounting therein a bar of steel having the same composition as the liquid steel and being coincident with the long axis of the casting, admitting the molten metal through a gate at the bottom of the mold, adding portions of the solid metal to the liquid metal as it rises in the mold, filling the sinkhead with the molten metal, covering the surface of the top of the liquid metal with an insulating mixture of compounds that react exothermally with iron oxides and oxygen, placing upon the exothermic mixture a dry charred wooden block with a hole in the center, and subsequently adding at intervals portions of the treated solid bodies to cause solidification of the liquid metal to advance upward at a rate so that the body of the roll is practically solid before the metal in the upper neck of smaller diameter has completely solidified, said solid metal being of a different chemical composition from that of the liquid metal that is cast.

5. The process of casting rolls of iron and steel, and of causing the liquid metal of which they are made to solidify upwards at a rate faster than the solidification in directions normal to the inner surfaces of the mold, the insertion of solid metal in the form of a bar and by the addition at intervals of portions of solid metal in the form of small bodies, which process involves the

steps of freeing the surfaces of the solid bodies from oxide and coating them to prevent them from rusting, forming a mold of the desired shape and dimensions with a suitable sinkhead, suspending a cleaned solid bar within the mold along the central axis of the casting, admitting the molten metal through a gate at the bottom of the mold, covering the top surface of the molten metal with an exothermic mixture, then lowering the remainder of the suspended bar downward through the sinkhead and the upper neck into the body of the roll, and subsequently covering the surface of the top of the liquid metal with an insulating mixture of compounds that react exothermally with iron oxides and oxygen, placing upon the exothermic mixture a dry charred wooden block with a hole in the center, and subsequently adding at intervals portions of the treated solid bodies to cause solidification of the liquid metal to advance upward at a rate so that the body of the roll is practically solid before the metal in the upper neck of smaller diameter has completely solidified, said solid metal being of a different chemical composition from that of the liquid metal that is cast.

6. The process of producing castings of iron and steel which consists of the steps of preparing a mold of the desired form and dimensions, said mold having a sinkhead with a refractory facing, heating the interior of the sinkhead to a high temperature, introducing the molten metal into the mold through a gate at the bottom until the mold is filled with the liquid metal, covering the surface of the liquid metal with a mixture of compounds that react exothermally with iron oxide and oxygen, and thereafter adding at intervals portions of solid metal, in the form of small scale-free bodies, to cause solidification of the liquid metal of the casting to progress upward at a faster rate than solidification advances in directions normal to the inner surfaces of the mold.

7. The process of making steel castings inhibiting formation of internal defects in the casting during solidification of the metal being cast, which comprises introducing molten metal into a mold, and adding solid pieces of steel proportioned as to time of additions and amount for controlling the rate of cooling of the metal in the mold by accelerating normal progressive upward solidification of the metal in the mold until the upward solidification of the metal substantially exceeds in rate the normal rate of lateral solidification, while maintaining the top portion of the metal in the mold freely fluid until after solidification of the remainder of the metal has been completed.

8. The process of casting ferrous rolls for inhibiting formation of internal defects and unsoundness in the finished casting during solidification of the metal being cast, which comprises introducing molten metal into a mold until the mold is filled, adding pieces of metal in solid form into the molten metal through the top of the mold so that the pieces are caused to sink into the metal through the top surface of the molten metal in the mold, proportioning the additions and amounts of the said pieces to the molten metal for effecting a controlled accelerated upward cooling and upward solidification rate of molten metal substantially more rapid than lateral cooling thereof, whereby the molten metal solidifies progressively upwardly from the bottom of the mold substantially faster than from the sides thereof, and maintaining the top of the

metal in the mold freely molten and free from solid crust until after solidification of the remaining metal in the mold has occurred.

9. The process of casting ferrous metal for inhibiting formation of internal defects and unsoundness in the finished casting during solidification of the metal being cast, which comprises introducing molten metal into a stationary open top mold, adding pieces of metal in solid form into the molten metal through the open top of the mold so that the pieces are caused to sink into the metal through the surface of the molten metal in the mold, and proportioning additions and amounts of the said pieces to the molten metal for effecting a controlled accelerated upward cooling and upward solidification rate of molten metal substantially more rapid than lateral cooling thereof, whereby the molten metal solidifies progressively upwardly from the bottom of the mold substantially faster than from the sides thereof, while causing the solid pieces being added to melt prior to their contacting the solidified metal, whereby solidification of the open top portion of the metal occurs only after solidification of the remainder of the entire remainder of the casting.

10. The process of producing ferrous metal castings, such as rolls or the like, which as cast and prior to removal from the mold having a top restricted neck and a bottom restricted neck with a body intermediate the necks greatly larger than the said necks, which comprises making a mold having approximately the configuration of the casting so that when the mold is filled, the metal will be cast into the aforesaid necks and body, filling the said mold with molten metal while maintaining the top restricted neck open, adding into the molten body of metal in the mold through the open top neck, pieces of metal in solid form, allowing the said pieces to sink through the body of metal in the mold, proportioning additions and amounts of the said pieces to the molten metal for effecting a controlled accelerated upward cooling and upward solidification rate of molten metal substantially more rapid than lateral cooling thereof, whereby the molten metal solidifies progressively upwardly from the bottom of the casting substantially faster than from the sides thereof, and maintaining the top restricted neck of the casting freely molten and freely open from solid crust until after the entire remaining casting is solidified.

11. The process of producing ferrous metal castings, such as rolls or the like, which as cast and prior to removal from the mold having a top restricted neck and a bottom restricted neck with a body intermediate to the said necks greatly larger than the said necks, which comprises making a mold having approximately the configuration of the casting so that when the mold is filled, the metal will be cast into the aforesaid necks and body, filling the said mold with molten metal while maintaining the top restricted neck open, introducing, in requisite installments into the molten body of metal in the mold, solid pieces of metal, allowing the pieces to sink into the body of metal in the mold to locations well below the top restricted neck, proportioning additions and amounts of the said pieces to the molten metal for effecting a controlled accelerated upward cooling and upward solidification rate of molten metal substantially more rapid than lateral cooling thereof, whereby the molten metal solidifies progressively upwardly from the bottom of the mold substantially faster than from the

sides thereof, while causing the solid pieces of metal being added to melt prior to contact with the solidified metal of the casting but always below zones of pipe and cavity formation in the casting, and maintaining the metal in the top restricted neck continuously freely molten and free from crust until after solidification of the entire remainder of the casting.

12. The process of producing ferrous metal castings, such as rolls or the like, which as cast and prior to removal from the mold having an open top restricted neck and a bottom restricted neck with a body intermediate to the said necks greatly larger than the said necks, which comprises forming a mold conforming approximately in size and shape to the size and shape of the resulting rough finished casting, with a sinkhead having a capacity not substantially more than the minimum required to compensate for total contraction of the casting, which comprises filling the mold with molten metal, preventing solidification of metal at its exposed surface by applying thereto, in order, coverings consisting of an exothermic mixture, a charred wood block, and powdered coking coal, permitting the metal to stand in the mold until a solid shell of metal is formed around the metal and mold wall, and subsequently to formation of such shell but while the remaining metal is still liquid, adding chemically clean solid metal in the form of small pieces and at controlled intervals and in controlled amounts for causing a controlled solidification of metal upwardly at a rate substantially greater than from directions normal to the wall of the mold.

13. The process of producing ferrous metal castings, such as rolls or the like, which as cast and prior to removal from the mold having an open top restricted neck and a bottom restricted neck with a body intermediate to the said necks greatly larger than the said necks, which comprises forming a mold conforming approximately in size and shape to the size and shape of the resulting rough finished casting, with a sinkhead having a capacity not substantially more than the minimum required to compensate for total contraction of the casting on solidification, the open top restricted neck being between the mold and sinkhead, filling the said mold with molten metal, and thereafter adding portions of clean solid metal, each portion being added at predetermined intervals of time while controlling the size of the pieces and intervals of time so that the added pieces of metal fuse in the metal as solidification thereof proceeds, and solidification of the metal advances progressively upwardly at a rate substantially faster than solidification proceeds horizontally, thereby maintaining the metal in the top restricted neck of the casting freely liquid until after solidification of the remainder of the casting.

14. The process of casting ferrous metal rolls having restricted neck portions and a relatively larger roll body portion, which comprises forming a mold of desired form and dimensions and having a cavity including a bottom restricted portion and an open top restricted portion, the restricted portions forming the neck portions of the roll, filling the mold with molten metal leaving an exposed upper surface thereof, covering the said exposed surface of the molten metal with an exothermic mixture, a charred wood block, and powdered coking coal for preventing solidification of the molten metal at its upper surface,

adding to the molten metal portions of solid metal in small pieces at varying intervals of time, controlling the weights and intervals of time of the additions of solid pieces so as to effect solidification of the metal below the said upper neck before a column of metal coincident with the central axis of the neck has solidified, and measuring the progress of the solidification by quickly inserting and withdrawing a gauge rod just prior to adding solid metal at later intervals for ascertaining the requisite amount of solid metal to be added.

15. The process of casting metal for inhibiting formation of internal defects and unsoundness in the casting during solidification of the metal being cast, which comprises introducing molten metal into an open top mold so that there is an exposed surface of the metal until the mold is filled, adding pieces of metal in solid form into the molten metal through the exposed surface of the mold so that the pieces are caused to sink into the molten metal to points beneath zones of formation of internal cavities of the casting, proportioning the additions and amounts of the said pieces for effecting a controlled accelerated upward cooling and upward solidifying rate substantially greater than lateral cooling of the metal, whereby the molten metal solidifies progressively upwardly from the bottom of the mold substantially faster than from the sides thereof, and maintaining the open top of the metal freely molten and free from crust until after solidification of the remaining metal in the mold, the additions of the solid pieces of the metal being made at predetermined time intervals of at least about 10 minutes, the total metal thus added being from between about 0.5% and about 2.0% of the weight of the casting, the weight of each portion added being less than about 0.2% of the weight of the casting, and the size of the pieces added being varied according to the time of addition and the size of the casting so that they will fuse with the cast metal preferably before solidification thereof.

16. The process of casting ferrous metal for inhibiting formation of internal defects and unsoundness in the finished casting during solidification of the metal being cast, which comprises introducing molten metal into a mold until the mold is filled, adding small pieces of metal in solid form into the molten metal so that the pieces contact the bottom portion of the molten metal in the mold, making predetermined additions of the pieces during predetermined time intervals for effecting a controlled accelerated upward cooling and upward solidification rate of molten metal substantially more rapid than lateral cooling thereof by abstracting heat by the solid pieces from the molten metal from the bottom thereof upwardly, whereby the molten metal solidifies progressively upwardly from the bottom of the mold substantially faster than from the sides thereof, and maintaining the top of the metal in the mold freely molten and at least substantially free from solid crust until after solidification of the remaining metal in the mold has occurred.

17. The process of casting ferrous metal for inhibiting formation of internal defects and unsoundness in the finished casting during solidification of the metal being cast, which comprises introducing molten metal into a mold until the mold is filled, adding small pieces of metal in solid form into the molten metal so that the pieces contact the bottom portion of the molten metal in the mold, and making predetermined

additions of pieces during the predetermined time intervals for effecting a controlled accelerated upward cooling and upward solidification rate of molten metal substantially more rapid than lateral cooling thereof by abstracting heat by the solid pieces from the molten metal from the bottom upwardly, whereby the molten metal solidi-

fies progressively upwardly from the bottom of the mold substantially faster than from the sides thereof.

CHARLES B. FRANCIS.
ROY H. NODERER.
RALPH B. PORTER.