Jan. 21, 1936. J. E. PERRY ET AL 2,028,243

INGOT MOLD FOR STEEL INGOTS

Filed July 5, 1923 3 Sheets-Sheet 1

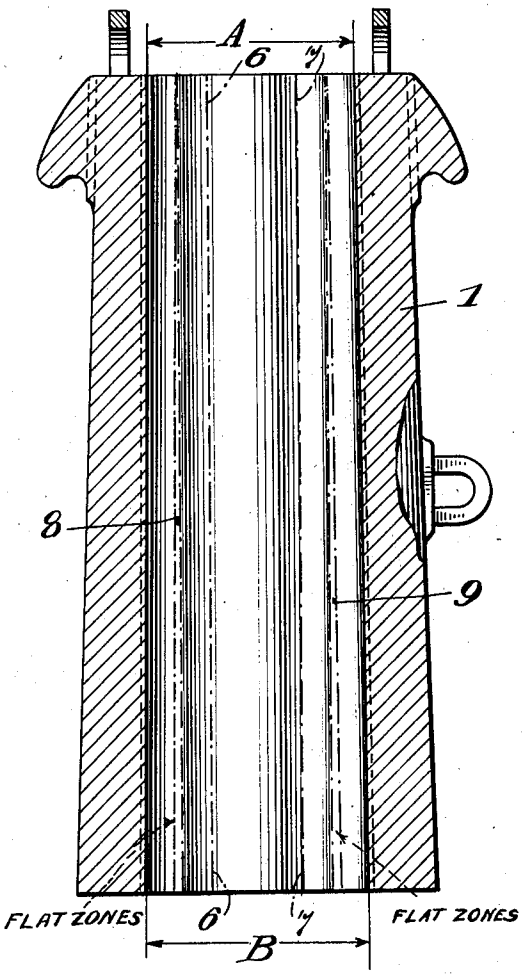


Fig. 1.

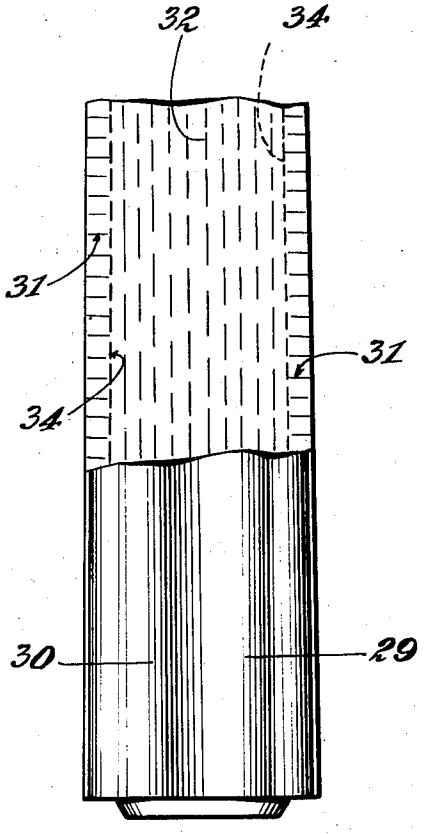


Fig. 4.

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Filed July 5, 1923 3 Sheets-Sheet 2

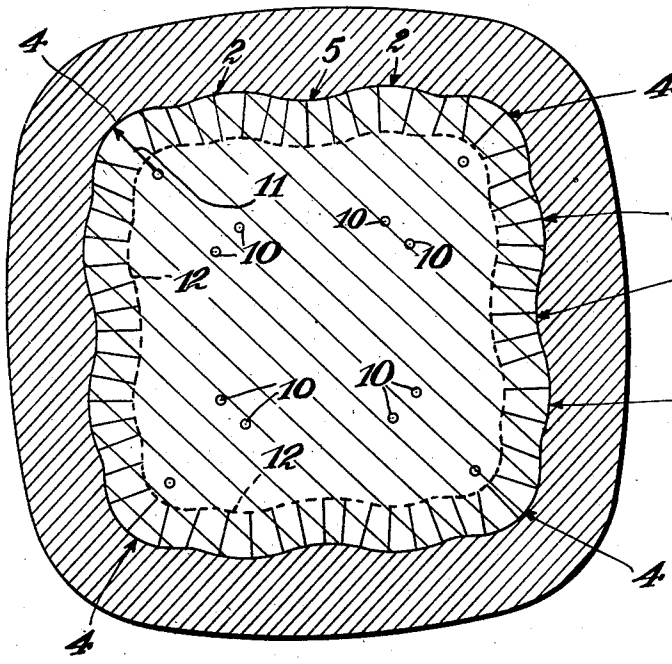


Fig. 2.

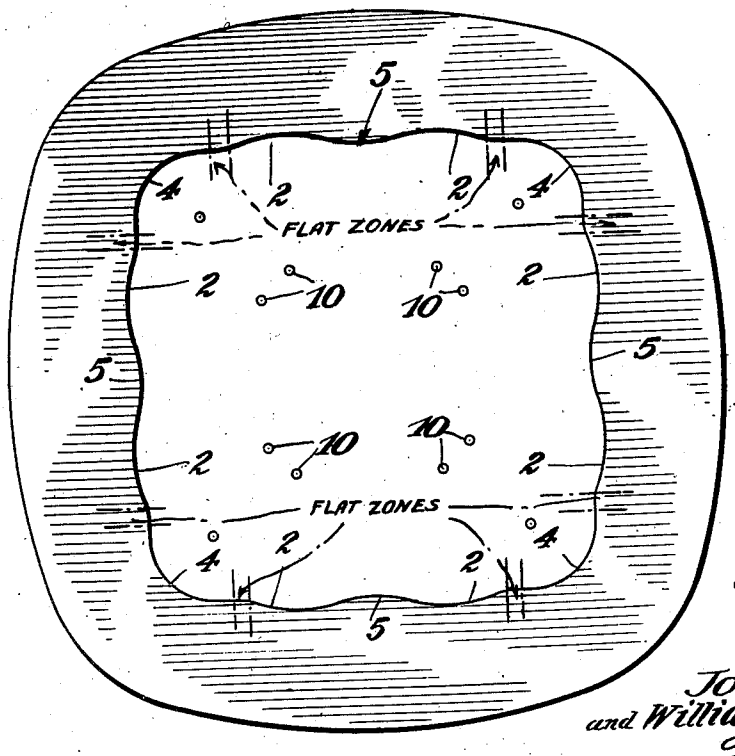


Fig. 3.

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Filed July 5, 1923 3 Sheets-Sheet 3

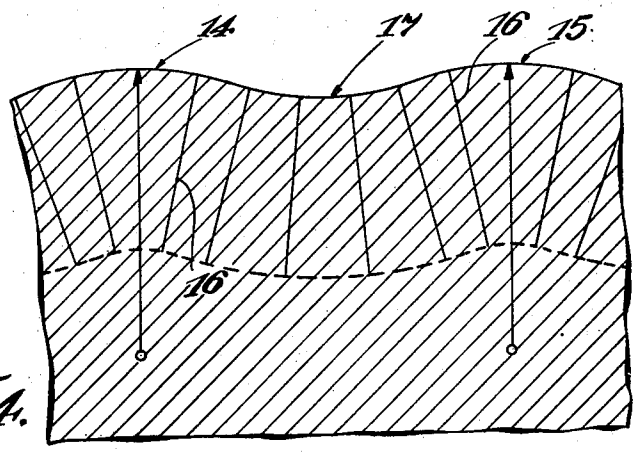


Fig. 4.

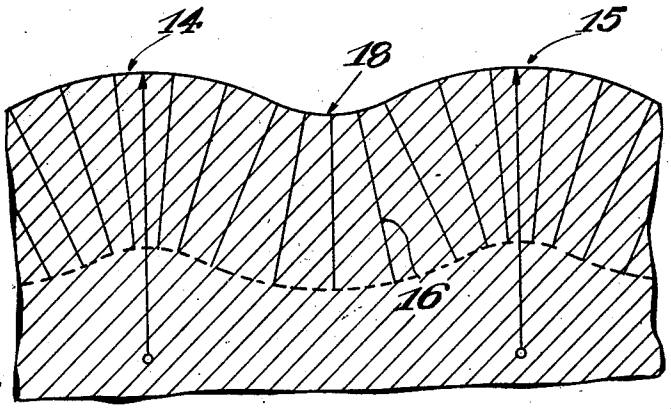


Fig. 5.

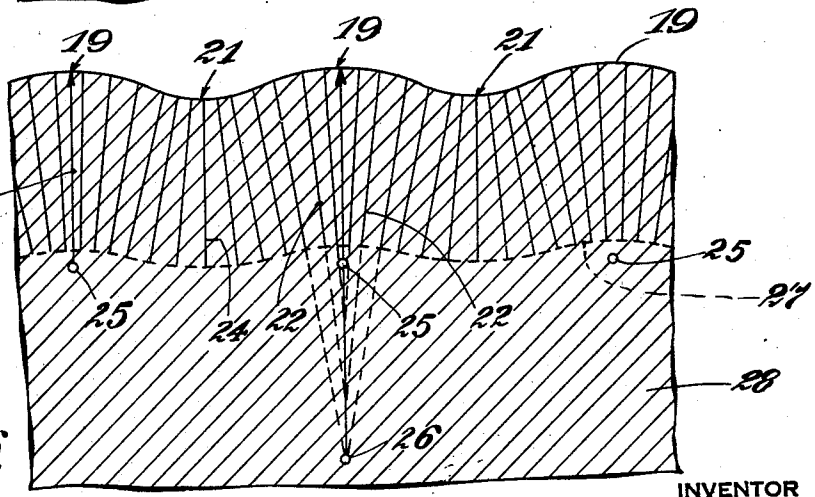


Fig. 6.

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UNITED STATES PATENT OFFICE

2,028,243

INGOT MOLD FOR STEEL INGOTS

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Application July 5, 1928, Serial No. 290,329

11 Claims. (Cl. 22—139)

The present invention relates broadly to the metallurgy of steel and more especially to ingot molds for the production of steel ingots without surface defects or undesirable crystallization adjacent the surface of the ingot.

Molten steel when poured into an iron mold first forms a very thin skin of fine grain crystals and then columnar crystals at substantially right angles to the mold which grow inward under the influence of the chill of the mold, and finally axial crystals extending substantially parallel to the mold wall complete the freezing of the ingot. Since molten steel has a greater volume than solidified steel, the frozen skin of the ingot adjacent the mold wall contracts and pulls away slightly from the matrix face of the mold wall. The ferrostatic pressure of molten steel in the ingot as well as shrinkage stresses exerts an internal pressure against this skin tending to strain and stretch it. In view of the fact a plane flat surface cannot elongate without stretching, the skin of the ingot may break and form external cracks. Since the bottom of the ingot cools rapidly some distance upward from the stool, the sides of the ingot in a zone above the cool base portion remain relatively hot and the skin on the ingot in this zone is therefore relatively thin. This is partially due to the fact that the ingot in shrinking pulls away from the side walls and interrupts the conductivity of heat to the side walls, and partly due to the bottom being cooled more than the sides because of the added chilling effect on the bottom due to the stool. As the mass of molten metal increases during pouring, the ferrostatic pressure of the molten steel may stretch this thin skin out against the side wall of the matrix and wedge the ingot to the mold or it may even cause a break through the skin in this zone of thin skin above the base of the ingot and a small leak of molten steel from the interior of the ingot through such breaks will cause a protuberance or button of steel to form between the skin of the ingot and the side wall of the mold. This button or protuberance quickly freezes and wedges the ingot tightly against the mold at this point. In either case, the vertical shrinkage of the ingot tends to lift the base of the ingot from the stool and cause the bottom portion of the ingot to hang suspended from the wedged portion. This causes horizontal cracks in the weak skin adjacent or beneath the buttons or projections referred to. These various surface cracks in the steel ingot are very undesirable in that oxidation occurs for the depth of the cracks and defects are thereby formed in the finished final product.

The present invention overcomes the difficulties of the prior art by providing longitudinally extending recesses in the side walls of the mold which form salients on the ingot that are joined by non-salient portions. These salients on the ingot preferably are in the form of low height waves or corrugations with the salient portions having larger radii than the non-salient portions that are between the salient portions. With salients of the prior art of small radii and of a substantial height from the side of the ingot there is a liability of trapping segregates in these salients due to the rapid formation of converging crystals in such old form of salients, since such salients chill quickly and permit the columnar crystals to focus at a point within the portion of the ingot which freezes directly under the influence of the chill from the mold wall.

Ingots having relatively high salients of small cross section formed on small radii not only trap segregates and cause weakness by entangled columnar crystals in the salients, but also tend to decarburize or burn on the tops of the salients when being reheated in the soaking pit for rolling or working. This results in a weakened longitudinal plane at the top of the salient and the fabricated articles show faults over these areas in the finished product corresponding to the crests of these small salients.

In the present invention the curvature of the recesses and ribs in the mold, forming salient and non-salient surfaces on the ingot, are of such form that the columnar crystals in the ingot which grow at substantially right angles to these surfaces do not tend to focus within the zone of direct chill of the mold.

The axes of the radii upon which the recesses and ribs of the mold are formed are so located that when the ingot is cast therein the columnar crystals, if extended, tend to come to a focus within the zone of axial crystals in the ingot. In other words, the radii of the salient recesses in the mold are such that during the freezing of the ingot, the ingot is entirely frozen before the columnar crystals have grown to such length that the inner ends of these crystals overlap or intersect with each other. This prevents trapping of the concentrates by the ends of columnar crystals as would occcur where the salients on the ingot are of such form as to cause these crystals to actually intersect and focus.

From a crystalline standpoint the radii of the non-salient portions on the ingot is not so im-

portant as the radius of the salient portions, but in practice it has been found that non-salient portions should be of such radii as to avoid surface defects which may occur in working the ingot when the non-salient portions are on very small radii and also to permit the free growth of these columnar crystals without bringing the inner ends of these crystals into interlacing contact with each other.

Another important feature of this invention resides in the mold matrix salient recesses, forming salients on the ingot, being parallel to each other and to center planes at right angles to the mid sections of the mold side walls. This produces salients on the ingot which pass in a straight line direction under the rolls of a rolling mill and prevent any cross or diagonal rolling on the surface of the ingot. The dimension of the salients being uniform throughout the length of the ingot permits uniform crystallization of the ingot for the full length of the ingot. This also obviates non-uniform casting and rolling strains on the salients and permits uniform heating of the salients when the ingot is in the soaking pit. Where the matrix of the mold is tapered, as may be the case in rectangular molds, the maintaining of these salient recesses of the same size throughout the length of the mold, and with the bottoms of the salient recesses parallel, may be accomplished by providing small flat narrow triangular areas on the sides of the matrix mold walls, and these areas are preferably located between the corner curved surfaces and the adjacent salient recesses.

The present invention also comprises a novel ingot of steel preferably having parallel salients on the ingot surface and with the salients having radii located within the portion of the ingot comprising the axial crystallization zone so that the columnar crystals do not come to a focus, but the inner ends of these crystals comprise a wavy zone surrounding and securely locked into the axial crystal center portion of the ingot.

With ingot molds of the improved construction, several other advantages also occur. Some of these advantages are that the corrugated side wall skin of the ingot during pouring and freezing can straighten out or elongate by flattening out the corrugations without causing longitudinal cracks, and since the radii of the salients are relatively large, the danger of adverse crystallization is overcome, and the danger of burning or decarburization of the tops of the large salients is also overcome since the mass of metal beneath the salients is sufficiently great to absorb heat which otherwise would burn the tops of salients of small radii. A further advantage is obtained by these large radii salients in that where long vertical ingots are being cast and the upper part of the ingot is maintained hot during the latter part of the pouring while the lower part is cooling and tending to rise from the stool, because of the upper part being hot and being tightly wedged to the upper portion of the mold, these ribs which have been chilled comprise stays or struts which are of sufficient strength to support the downward vertical ferrostatic pressure of the molten steel in the ingot and also vertical shrinkage, thereby also obviating the undesirable horizontal or "hang" cracks.

Increased height of salient on an ingot gives increased strength of ingot skin. In rolling practice, however, there is a maximum height which is allowable for any given cross-sectional size of ingot. Moreover, the size of ingot determines the number of proper salients which may be placed in the side thereof. Using this proper number of salients and with the form of curvature such as will produce correct crystallization, the maximum height of salient is obtained by having the non-salient radius relatively small.

Other and further objects of this invention will in part be obvious and will in part be pointed out hereinafter by reference to the accompanying drawings forming a part of this specification.

Realizing that the present invention may be embodied in structures other than those specifically disclosed, it is to be understood that the disclosure herewith is illustrative and not in the limiting sense.

Fig. 1 is a longitudinal section of the mold in accordance with the present invention and wherein the flats on the sides of the mold are shown exaggerated in order to be indicated on the drawings.

Fig. 2 is a cross sectional plan view of the upper portion of a mold with an ingot cast therein in accordance with the present invention.

Fig. 3 is a bottom plan view of the lower end of the mold illustrated in Fig. 2.

Fig. 4 illustrates detailed portion comprising a section adjacent one side of an ingot in accordance with the present invention, and with the salients joined by long non-salient portions.

Fig. 5 is a view similar to Fig. 4 showing these salients joined by a short non-salient portion.

Fig. 6 is a view similar to Figs. 4 and 5, and wherein the salients are of small radii but low depth.

Fig. 7 is a longitudinal view of a rectangular ingot in accordance with the present invention showing a portion of the ingot broken away to more clearly illustrate the relation between the columnar and axial crystals.

Referring now to the drawings and more especially to Figs. 1, 2, and 3, Fig. 1 illustrates a longitudinal or vertical cross section through a mold in accordance with the present invention. The mold walls **1** are provided with salient recesses **2**, which are illustrated in the present case as comprising two salient recesses (which number may be increased as desired) between each corner surface **4**, and joined at the mid section of the side wall of the mold by a non-salient rib **5**. These salient recesses on the same side of the matrix have their bottom portions extending parallel throughout the length of the mold, as is indicated by lines **6** and **7** in Fig. 1. These salient recesses, therefore, form parallel salients on an ingot cast in the mold. In view of the fact that the molds as illustrated herewith are slightly tapered and the bottom width of the matrix is slightly greater than the top thereof, flat surfaces **8** and **9** (shown in Fig. 1 in exaggeration) occur between the corner surfaces **4** and the adjacent salient recesses **2**. These surfaces are referred to as "flat" but it is understood that the term "flat" is merely relative. They may be somewhat curved, and the construction which is emphasized is that the salient recesses are made parallel without distortion of the corner surfaces, and with the salient recesses being of substantially the same width and height throughout the length of the mold.

An extremely important feature of the present invention resides in the fact that the salient recesses **2** and non-salient ribs **5** are so formed that the growth of the columnar crystals in an ingot while freezing in a matrix will not focus within the zone of mold wall chill. In the preferred em-

bodiment of the invention, the axes 10 of the radii 11 are within the zone of axial crystals of the ingot and beyond the normal effect of chill of the mold on the crystallization of the ingot. This insures that the columnar crystals which grow at substantially right angles to the surface of the mold do not come to a focus and therefore do not trap inclusions.

A further advantage of this construction is that the zone where the columnar crystals meet the axial crystals in the ingot is such that these two types of crystals interlock with each other in an interlocking zone which thoroughly ties the two types of crystals together. This zone is indicated on Fig. 2 by the dotted line 12, but it is to be understood that the zone is of a relatively substantial width so that the dotted line indicates the general rather than the absolute definite location of the zone.

Fig. 3 illustrates the bottom of the matrix shown in Fig. 2 and shows the salient recesses 2 and non-salient ribs 5 to be of the same size and shape throughout the length of the mold.

Fig. 4 is a detailed section of a portion of an ingot adjacent the surface cast against the salient recesses and showing the salients 14 and 15, which are on radii of the same length, the axes of which radii are located well within the zone of axial crystals 16. The non-salient portion 17 is formed on a relatively long radius and is tangent at its extremities to the curves of the salients 14 and 15.

Fig. 5 is a view similar to Fig. 4 with salients 14 and 15 thereon being formed of the same radii as shown in Fig. 4. The non-salient portion 18 however, is upon a shorter radius. This forms a deeper salient and provides additional stiffening in the ingot while the ingot is freezing. This view illustrates the crystallization from surfaces having the salient portions maintained at proper radii and with the non-salient portion being relatively small.

Fig. 6 illustrates small salients 19 formed upon radii 20, the axes of which are located within the chill zone and with non-salient portions 21 joining the salient portions so that the height of the salients is relatively low. While as above specified, the columnar crystals tend to grow at substantially right angles to the mold wall surface, the actual growth of these crystals is influenced somewhat by the adjoining surface, as, for example, in Fig. 6, the growth of the columnar crystals 22 from the salients 19 is influenced by the growth of the columnar crystals 24 from the non-salient portions 21. Under these conditions a very few of the columnar crystals 22 growing from the salients 19 tend to focus at the axes 25 of the radii 20 but the influence of the growth of the columnar crystals 24 adjacent the salient crystals 22 permits a slight swinging outward of these columnar crystals 22 so that instead of focusing at the axis 25 the majority of these columnar crystals extend in a direction which would focus at the point 26 and some of the columnar crystals 22 tend to focus along the entire line between the point 26 and the axis 25 of the radii. It will be observed, however, that the extreme length of a columnar growth terminates substantially at a depth on which the axes 25 are located so that since these crystals do not grow beyond the depth indicated by the line 27, there is no substantial interlacing or focusing of any substantial amount of the columnar crystals 22 within the zone of the direct chill from the side wall of the mold. This condition obviates any cleavage plane being formed in the columnar crystal area in view of the fact that a substantial majority of the columnar crystals 22 if extended would focus within the area 28 which represents the axial crystals of the ingot.

Fig. 7 illustrates a portion of an ingot according to the present invention with the sides of the ingot being provided with salients 29 and 30 which run parallel, and with the columnar crystal zone 31 adjacent the sides of the ingot, and with the axial crystal zone 32 in the central portion of the ingot, and with the interlocking zone 34 intermediate the columnar crystals and the axial crystals.

The present invention produces ingots having not only improved skin surfaces, but also are better ingots from a metallurgical standpoint in that the ingots freeze under conditions which obviate harmful internal stresses and the several forms of steel crystals comprising the ingot are permitted to form more freely and to more freely interlock with each other without trapping harmful inclusions at the juncture between the portion of the ingot directly influenced by the chill from the mold and the central portion or non-chilled zone in the interior of the ingot.

Having described our invention, we claim:

1. In a vertical ingot mold, a matrix having salient recesses and non-salient ribs in the side wall thereof, said recesses extending longitudinally of said matrix and being of uniform width throughout the length of the mold, and with one end of said matrix being of larger cross sectional area than the other end.

2. In a vertical ingot mold, a matrix having salient recesses and non-salient ribs in the side wall thereof, said recesses extending longitudinally of said matrix and being of uniform depth throughout the length of the mold, and with one end of said matrix being of larger cross sectional area than the other end.

3. In a vertical ingot mold, a matrix having salient recesses and non-salient ribs in the side wall thereof, the corners of the matrix being on a uniform radii throughout the length of the matrix, the bottom portions of said recesses on one side of said matrix being parallel throughout the length of said mold, and with said matrix tapering from one end toward the other.

4. In a vertical ingot mold, a matrix having salient recesses and non-salient ribs in the side wall thereof, the bottom portions of said recesses on one side of said matrix being parallel throughout the length of said mold, each of said recesses being of uniform depth throughout its length, and with said matrix tapering from one end toward the other.

5. In a vertical ingot mold, a matrix having salient recesses and non-salient ribs in the side wall thereof, the bottom portions of said recesses on one side of said matrix being parallel throughout the length of said mold, each of said recesses being of uniform width and depth throughout its length, and with said matrix tapering from one end toward the other.

6. In a vertical ingot mold for casting steel ingots, a matrix portion having a vertical taper and with salient recesses and non-salient ribs on the side walls thereof, the corners of said matrix being rounded and tapering flat zones between the corners and the adjacent salient recesses.

7. In a vertical ingot mold for casting steel ingots, a matrix portion having a vertical taper

and with salient recesses and non-salient ribs on the side walls thereof, the corners of said matrix being rounded and tapering flat zones between the corners and the adjacent salient recesses, said salient recesses located on the same side of said matrix all being parallel throughout the length of said mold.

8. In a vertical ingot mold for casting steel ingots, a matrix portion having a vertical taper and with salient recesses and non-salient ribs on the side walls thereof, the corners of said matrix being rounded and tapering flat zones between the corners and the adjacent salient recesses, said salient recesses located on the same side of said matrix all being parallel and of uniform depth throughout the length of said mold.

9. In a vertical ingot mold for casting steel ingots having a matrix with longitudinally extending salient recesses and non-salient ribs in the side wall thereof, the matrix being tapered from one end of the mold to the other, said recesses and ribs being of uniform depth, width, and curvature throughout the length of the mold, the corners of said matrix being rounded and with narrow flat triangular zones adjacent said corners.

10. In a vertical ingot mold for casting steel ingots having a matrix with longitudinally extending salient recesses and non-salient ribs in the side wall thereof, the matrix being tapered from one end of the mold to the other, said recesses and ribs being of uniform depth, width, and curvature throughout the length of the mold, the corners of said matrix being rounded on a uniform radius throughout the length of the mold, and with narrow flat triangular zones adjacent said corners.

11. An ingot mold having a longitudinally tapered matrix with salient recesses and non-salient ribs on the walls thereof, the corners of the matrix being of uniform radius throughout the length of the matrix, the salient recesses in the side walls being formed on a uniform radius throughout the length of the matrix, and the axes for the radii of the salient recesses on a side of the matrix being parallel to each other.

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