Dec. 27, 1932. E. GATHMANN 1,892,569

INGOT

Filed Oct. 27, 1932

Fig. 3.

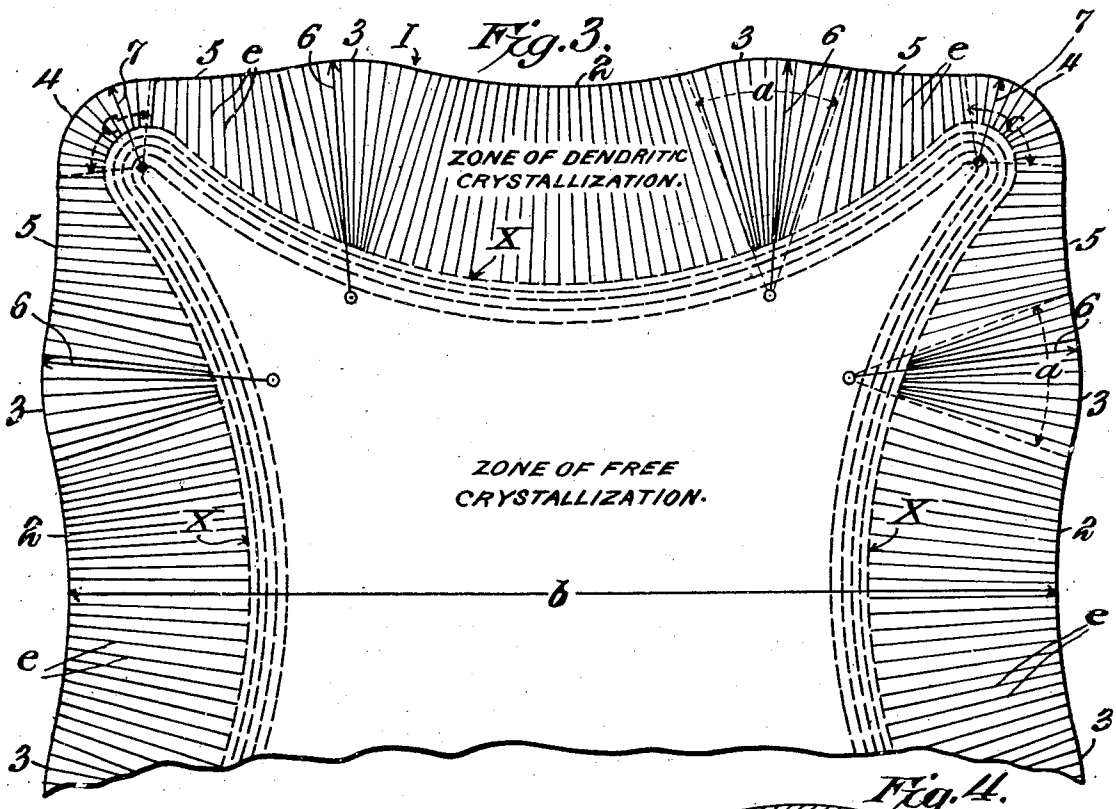


Fig. 1.

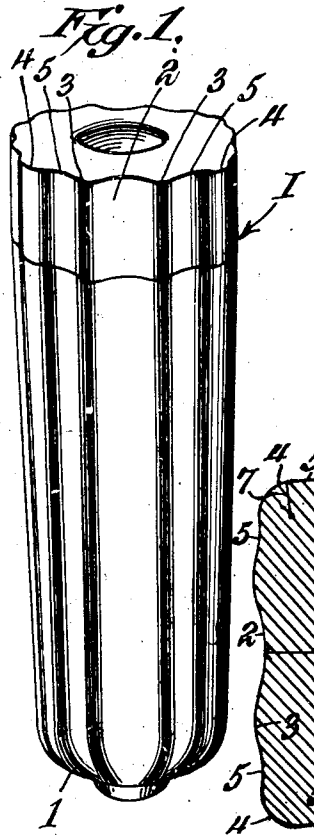


Fig. 4.

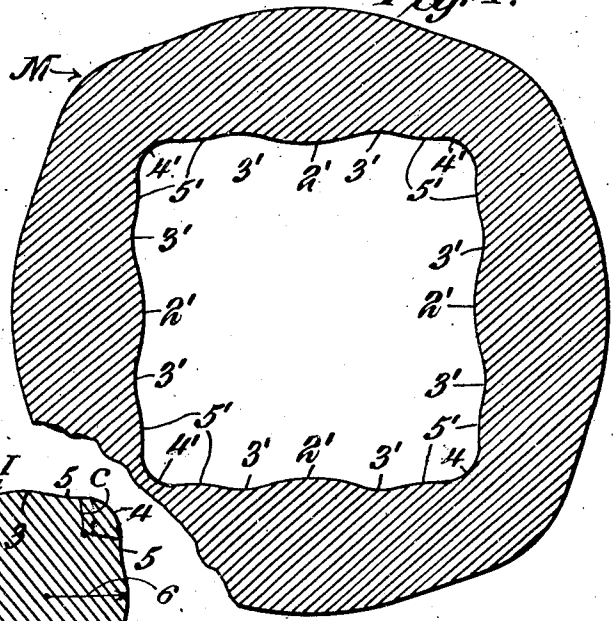
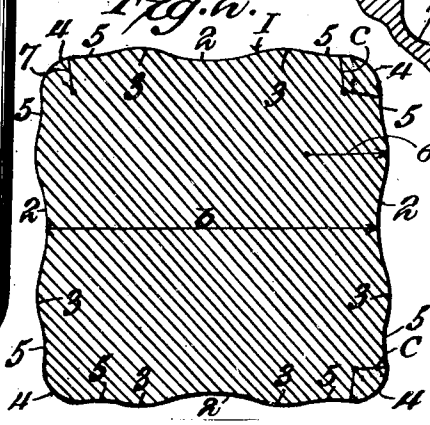


Fig. 2.



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Patented Dec. 27, 1932 1,892,569

UNITED STATES PATENT OFFICE

EMIL GATHMANN, OF BALTIMORE, MARYLAND

INGOT

Application filed October 27, 1932. Serial No. 639,889.

This invention relates to metallic ingots and more particularly to improvements in ingot surface contours whereby sound ingot crystalline structure may be obtained, the contours, at the same time, being such as to provide for most efficient reduction of the ingot in the rolling process.

When molten steel is poured into a metallic ingot mold, it solidifies through the formation of dendritic and free or equiaxial crystals, due to the absorption of heat by the surrounding mold walls. The ingot metal immediately adjacent the mold walls is cooled rapidly and crystallizes in the form of dendrites, which grow into the mother liquid at right angles to the mold walls. As the dendrites progress in their growth and the temperature of the liquid adjacent the dendritic structure is lowered, the formation of free or equiaxial crystals begins. As explained in my co-pending application Serial No. 547,998, filed June 30, 1931, the ratio of the depth in cross section of the ingot metal comprising dendritic crystalline structure to the cross sectional width of the ingot as a whole depends upon such factors as the pouring temperature and the cross sectional area of the ingot, and, depending upon the latter factor, the depth of the area of dendritic crystallization, with ordinary commercial pouring temperatures, is from one-sixth to one-fifth of the cross section of the ingot considered as a whole.

The dendritic crystals grow in lines perpendicular to the mold walls defining the contour of the ingot, and, where the contour near the mid portions of the ingot sides is shaped by relatively small radii, resulting in relatively small curved convex surfaces on the ingot, the lines of dendritic crystallization extending inwardly from such surfaces will intersect within the zone of dendritic crystallization. This often results in the formation at their focal points of what are known as cleavage planes, which are zones of weakness in the ingot structure.

In my co-pending application Serial Number 547,998 referred to above, I disclosed and claimed an ingot having outwardly curved side wall portions the radii of which are of such length that the centers from which the wall portions are described lie within the zone of free crystallization.

While it is important that the centers from which the corners are described also lie within the zone of free crystallization, it is equally as important that the radii of the ingot corners be not too large; otherwise trouble will be experienced during rolling of the ingot, since too wide a corner wall will result in the formation of laps and tears during rolling. Theoretically, considering the corner contour from a standpoint of rolling alone, a very small corner radius would be best. There are, however, two practical considerations which limit definitely the abruptness of the corner curvature, these being: First, that the corner should not be so sharp as to render this portion of the ingot unduly susceptible to burning during the reheating process; and, second, that, in order to avoid the formation of cleavage planes adjacent the ingot corner walls, the centers from which these walls are described should be located inwardly beyond the zone of dendritic crystals, that is, should be located within the zone of free equiaxial crystals.

As the corners of the ingot break contact with the mold corner walls soon after the formation of the initial solid ingot skin due to differential shrinkage and expansion of the ingot and mold respectively, the dendritic crystals do not extend as far inwardly at the corners of the ingot as they do adjacent outwardly curved portions of the sides. Microscopic studies of etched cross sections of ingots produced in commercial practice have disclosed that, at the corners of an ingot, the dendritic crystals extend inwardly a distance equal to about one twentieth the cross sectional dimension of the ingot as a whole; and I have found that for this reason the radii of the ingot corner walls need not be so great as the radii of other outwardly curved portions of the ingot surface, and by virtue of this fact it is possible to employ a relatively abrupt curvature at the ingot corners so as to provide for most efficient rolling and at the same time to locate the foci of the corner walls within the zone of free crystals, there-

by preventing the formation of cleavage planes.

Accordingly an object of the invention is to provide an ingot of such contour that the foci of the arcs defining convex portions of the ingot surface lie within the zone of free crystallization of the ingot metal, but at the same time the radii of the arcs defining the ingot corners are as small as is consistent with the requirements for sound solidification, so that the ingot may be reduced efficiently by rolling. More specific objects will become apparent from a reading of the following description, the appended claims, and the accompanying drawing, in which:

Figure 1 is a perspective view of an ingot having a contour in accordance with the present invention;

Figure 2 is a horizontal cross sectional view taken on the line 2—2 of Figure 1;

Figure 3 is a view on an enlarged scale showing graphically in horizontal cross section the relation of the various radii of the arcs defining curved portions of the ingot shown in Figures 1 and 2 to the zones of dendritic crystals and free equiaxial crystals; and

Figure 4 is a horizontal sectional view of an ingot mold suitable for use in producing ingots having a contour such as that of the ingot shown in Figures 1 and 2.

The invention may be embodied in various types of ingots, including big-end-up and big-end-down ingots cast either with or without shrink head portions. For the purposes of illustration, there is shown in the drawing an ingot I of the big-end-up type cast, for example, in a Gathmann mold and necked in at the bottom as at 1. The ingot may be cast with a shrink head portion, but as illustrated is cast without a shrink head, for example, in accordance with the method of producing metallic ingots disclosed and claimed in my copending application Serial No. 621,100, filed July 6, 1932.

As previously stated, the invention resides in the provision of a novel contour of ingot cross section adapted both to provide for efficient solidification without the formation of cleavage planes or similar defects, and at the same time to be adapted for most efficient reduction by rolling. The preferred contour in accordance with the present invention is shown best in Figures 2 and 3 of the drawing, from which it will be noted that the ingot cross section is of generally rectangular contour and is defined by four primary sides 2 each flanked by a pair of outwardly arched intermediate salients 3 which are connected to outwardly arched primary corners 4 by means of secondary corner portions 5, which preferably are arched inwardly. It is desirable that the outwardly arched salients 3 be subtended by angles a of less than sixty degrees. The primary sides 2 are relatively narrow as compared to the minimum width b of the ingot cross section as a whole, the sides 2 preferably being approximately one third the width b. As explained in my prior Patent 1,745,089, of January 28, 1930, it is desirable that the primary sides be relatively narrow, and that the outwardly extending flanking salients 3 be initially roll-contacting in order that the metal near the central portion of the ingot be compressed initially to a greater degree in a transverse direction during the initial roll passes than the metal adjacent the corners of the ingot. This lessens the longitudinal flow of metal during reduction by rolling, and the danger of transverse cracks occurring in the unworked portions of the ingot is reduced greatly. The initial mill passes serve not only to reduce the primary inwardly arched sides 2 and the secondary corner portions 5, but also to work and reduce the outwardly arched primary corners 4, so that the entire surface of the coarse crystalline structure of the cast metal is worked and refined or reduced to a forged rectangular structure before any considerable elongation of the ingot takes place. In this way tearing of the ingot surface due to elongation strains or checks of coarse unworked crystals is practically eliminated.

Figure 3 shows graphically the crystalline growth of metal comprising an ingot having the contour shown in cross section in Figure 2. The dotted line X in Figure 3 denotes the juncture of the central zone of free equiaxial crystals and the outer annular zone of dendritic crystals. As disclosed in my copending application Serial No. 547,998 referred to above, the zone of dendritic crystallization adjacent the sides of the ingot extends inwardly for a distance equal to between one-fifth and one-sixth of the cross section b of the ingot as a whole. Since the dendrites grow inwardly from the mold walls along lines e perpendicular to the side walls of the ingot, the centers of the arcs defining the outwardly curved salients 3 are located within the zone of free crystallization in order to prevent meeting of the lines of dendritic crystalline growth within the zone of dendrites. Therefore the radii of the arcs defining the salients 3 are of a length greater than one-sixth the cross sectional width b of the ingot, and preferably are about one-fifth of the width b. On the other hand, as determined by studies of etched sections of ingots produced in commercial practice, the zone of dendritic crystallization adjacent the corners 4 of the ingot does not extend inwardly so far as it does adjacent the primary sides. Although the inward extent of the dendritic zone adjacent the corners will vary slightly in accordance with the pouring temperature and other factors, I have ascertained from studies of etched sections that, in the case of ingots produced under usual commer-

cial conditions, the zone of dendrites adjacent the corner walls extends inwardly for a distance equal to about one-twentieh of the cross section *b* of the ingot. It is because of this fact that it now is possible, in accordance with the present invention, to provide an ingot having a contour adapted to produce the soundest crystalline structure in the ingot as cast, and at the same time to employ relatively small or narrow corners which are adapted for most efficient reduction in rolling. To this end the radii 7 of the arcs defining the primary corners 4 are of a length not greater than one-tenth and not less than one-twentieth of the cross section *b* of the ingot, the radii 7 preferably being of a length equal to approximately one-twelfth the cross section *b*. With the corner radii of a length within the limits referred to and preferably of a length of approximately one-twelfth of the cross section *b*, the lines of growth of the dendrites will meet within the zone of free equiaxial crystallization, thus preventing the formation of cleavage planes and other defects during solidification; and at the same time the corners are small enough to provide for efficient reduction of the ingot cross section during rolling without the formation of laps or tears, the corners, however, not being so sharply rounded as to result in burning thereof during the reheating process. Primarily for the purpose of obtaining the most efficient reduction of the ingot cross section during rolling, the corners 4 are subtended by angles *c* materially greater than ninety degrees, and preferably are subtended by angles between ninety and one hundred degrees, an angle of approximately ninety-five degrees having been found to produce the best results in most cases. In order that the secondary corner portions 5 be of not too sharp curvature, and at the same time to enable the employment of relatively small corners 4 subtended by angles of about ninety-five degrees, the corners 4 preferably are flattened out slightly where they meet the adjacent secondary corner portions 5, it being understood that the flattened portions constitute part of the corners 4.

Figure 4 shows in cross section an ingot mold M, preferably constructed of heat absorptive material such as cast iron, which may be employed for producing ingots having the contour shown in Figures 1, 2, and 3. The contour of the walls defining the ingot-forming chamber of the mold M corresponds exactly with the contour of the ingot, and therefore it is not necessary to describe the mold wall contour in detail. For convenience, however, portions of the mold walls corresponding to the various portions of the ingot surface described above are designated by corresponding reference characters, with the exception that the reference characters applied to the showing of the mold in Figure 4 are primed. For example, the primary side walls 2′ of the mold chamber correspond to and are of the same contour as the primary sides 2 of the ingot, and the primary corner walls 4′ of the mold correspond to and are of the same contour as the primary corners 4 of the ingot.

It will be understood that in the designing of metallic ingots it must be borne in mind that the ultimate product put to commercial use consists of shapes which are completed only after the ingot has been reduced by rolling or forging, and that the production of an ingot of sound crystalline structure in the mold, although essential to soundness in the finished product, does not in itself assure a sound final product. The ingot contour of the present invention is designed not only to produce sound crystalline structure in the ingot, but also to be adapted for efficient working of all portions of the ingot during the rolling process, so that, the ingot as cast being of sound crystalline structure, a minimum of defects will be produced during the rolling process subsequent to completion of solidification in the mold.

I claim:

1. A metallic ingot of generally rectangular cross section having sides and outwardly arched corners interposed between and connecting said sides, the radii of said outwardly curved corners being of a length less than one tenth but greater than one twentieth of the minimum cross sectional dimension of the ingot and the arcs defining said outwardly curved corners being subtended by angles materially greater than ninety degrees.

2. A metallic ingot of generally rectangular cross section having sides and outwardly arched corners interposed between and connecting said sides, the radii of said outwardly curved corners being of a length less than one tenth but greater than one twentieth of the minimum cross sectional dimension of the ingot and the arcs defining said outwardly curved corners being subtended by angles not less than ninety degrees and not more than one hundred degrees.

3. A metallic ingot of generally rectangular cross section having sides and outwardly arched corners interposed between and connecting said sides, the radii of said outwardly curved corners being of a length equal to about one twelfth the minimum cross sectional dimension of the ingot and the arcs defining said outwardly curved corners being subtended by angles materially greater than ninety degrees.

4. A metallic ingot of generally rectangular cross section having sides and outwardly arched corners interposed between and connecting said sides, the radii of said outwardly curved corners being of a length equal to about one twelfth the minimum cross sectional dimension of the ingot and the arcs defin-

ing said outwardly curved corners being subtended by angles not less than ninety degrees and not more than one hundred degrees.

5. A metallic ingot of generally rectangular cross section having four sides, at least two opposed sides each including an inwardly curved portion and a pair of outwardly curved portions flanking said inwardly curved portion, the radii of said outwardly curved portions being at least one fifth the minimum cross section of the ingot; and four outwardly arched corners respectively intervening between and connecting adjacent sides, the radii of said corners being less than one tenth but greater than one twentieth of the minimum cross sectional dimension of the ingot.

6. A metallic ingot of generally rectangular cross section having four sides, at least two opposed sides each including an inwardly curved portion and a pair of outwardly curved portions flanking said inwardly curved portion, the radii of said outwardly curved portions being at least one fifth the minimum cross section of the ingot; and four outwardly arched corners respectively intervening between and connecting adjacent sides, the radii of said corners being less than one tenth but greater than one twentieth of the minimum cross sectional dimension of the ingot, and the arcs defining said corners being subtended by angles materially greater than ninety degrees.

7. A metallic ingot of generally rectangular cross section having four sides, at least two opposed sides each including an inwardly curved portion and a pair of outwardly curved portions flanking said inwardly curved portion, the radii of said outwardly curved portions being at least one fifth the minimum cross section of the ingot; and four outwardly arched corners respectively intervening between and connecting adjacent sides, the radii of said corners being equal to approximately one twelfth of the minimum cross sectional dimension of the ingot.

In testimony whereof, I have hereunto subscribed my name.

EMIL GATHMANN.