Illustrative embodiments of the invention are shown on the accompanying drawings, in which:

FIGURE 1 is a conventionalized diagram representing an upright section of an ingot casting apparatus with devices according to the present invention for delivering core elements thereto during the casting operation;

FIGURE 2 is a perspective view, with parts broken away, of a mold-sealing platform with a core clamping device;

FIGURE 2A is a perspective view of a locating and clamping wedge element for FIGURE 2;

FIGURE 3 is a perspective view of a second form of practice employing a static ingot mold showing a core-locating arrangement;

FIGURE 4 is a perspective view of the blocks of the upper core-clamping devices of FIGURE 3, the blocks being separated for clearness;

FIGURE 5 is an upright section through a casting device substantially on line 5—5 of FIGURE 3;

FIGURE 6 is a conventionalized diagram of a third embodiment of the invention, representing an upright section with the parts in position for casting a cored ingot;

FIGURE 7 is a view corresponding to FIGURE 6, with parts in position for leading new core members;

FIGURE 8 is a section substantially on line 8—8 of FIGURE 7, showing parts of tension rollers;

FIGURE 9 is a perspective view of part of a produced ingot, with projecting core pieces;

FIGURE 10 is a diagrammatic view of a manner of removing a core piece.

In FIGURES 1 and 2, a continuous ingot casting apparatus is conventionally shown as having a pit 10 below a floor level 11, with a casting mold 12 secured at the floor level and served by a casting trough or tundish 13 above it. This tundish has an aperture through which the core strip or strips 20 may move downward; and is shown with the drop tubes 13a for conducting the molten ingot metal downward into the mold space. A platform 14 can seal the bottom of the mold 12 when the platform has been raised thereagainst by a hydraulic ram 15. The mold has water-cooling passages in its walls, and is served by the supply and discharge pipes 16. During the casting operation, molten metal from the tundish 13 provides a liquid level in the mold 12; as the metal chills and solidifies, the ram 15 is caused to descend with its platform 14, so that the solid metal descends as an ingot 17 in the course of formation.

To form a core or cores within the ingot, a core strip or strips 20 are unwound from a supply coil 24 and threaded through the structure, with the end passing through the platform and held by clamping and sealing devices as described hereinafter. Illustratively, the strips 20 are held in a vertical plane in the mold, and hence the course of only one strip need be described.

From the coil 21 and the strip 20 passes between pinch rolls 22. Braking means such as devices 23, 24 on the reel and on the rolls are employed, noting that in many cases either one may be used alone to ensure maintenance of some tension along the strip 20. The strip then passes through a set 25 of leveling or straightening rolls which reduce the strip 20 to a plane for further downward movement. The strip 20 then passes through a preheating furnace 25, where it is heated to above the volatilization temperature of the vehicle employed for a slurry which is thereafter sprayed upon both sides of the strip from the nozzles 27. The strip then passes between a second set of rollers 30 effective to maintain the alignment of the strip, and thence downward through the tundish 13 and into the mold 12. It is preferred to provide a severing device such as the shear blades 31 above the level of the tundish 13; and to have shield walls 29 to prevent discharge of loose slurry material into the mold.
Preheating burners 26a may be provided to heat the strips 20 to temperature approximating that of the ingot being poured; and thereby reduce the tension efforts required to prevent warpage of the cores by differential heating effects. With aluminum ingots, a dull red heat temperature for the core strips 20 is desirable, noting that under some pouring conditions, e.g., with very thin core strips, the heating from the tundish and the metal therein is sufficient. In other cases, temperatures up to 1100 degrees F. may be employed with aluminum; and corresponding temperatures with other metals. For example, with core strips 4 inches thick and 0.125 inch thick, a tension of 500 pounds is sufficient to maintain linearity; compared with 5000 pounds with cold cores.

A clamp for the core strip is provided at the lower end of the mold. As shown in FIGURE 2, the platform 14 may have a raised portion 51 on its top, for closely fitting the bottoms of the mold walls for accurate original location. The strips 20, part of one of which is shown in this fragmentary view, extend downwardly through the platform 54 and along a plane face 53 of a downward projecting wall 54 thereof. The opposed wall 55 has a tapered face 56 with upward convergence, to receive a wedge block 57 of corresponding shape and engage a plane face 58 for engaging the strip 20 and clamping it against the face 53. To assure proper and accurate spacing of the strips 20 relative to one another, the wedge block 57 may be provided, FIGURE 2A, with upright ribs 48 between the faces 58 for the individual core strips and spaced by distances equal to the core widths; wherewith change of these wedge blocks enables the making of ingots having varying sizes and numbers of cores with employment of the same platform 14. The walls 54, 55 are preferably joined to form a wall enclosing the sides and ends of the core strips 20 and locating the same relative to one another and to the mold walls for a specific core width: when a core of a slightly lesser width is employed, crevices may exist at the edges thereof. Any crevices at the upper surface of the platform may be sealed by a refractory, such as clay, to form a fillet 49 so that the ingot can be easily separated from the platform.

With the core strip in position in the mold 12 and its tundish 13, and held to the platform 14, and with this platform closing the bottom of the mold, the molten ingot metal is poured. The core strip can be preheated by a burner before the metal is poured. The portion is preferably effected at multiple points concurrently so that equal volumes of metal of the same temperature and heat content are delivered simultaneously at both sides and at the ends of the core, to avoid warpage due to thermal expansion. When the first poured metal has cooled to a solid, the ram 15 is started in movement downward, drawing the lower part of the ingot with it. The rate of downward movement of the ram and its platform, and the rate of pouring of molten metal, are correlated so that a hardened portion of the ingot remains in the mold as a dam and receptacle for later-poured metal. It is preferred to employ nozzles 18 to direct water sprays upon the ingot as it issues from the mold, thereby cooling it and, by heat conduction downward in the ingot, assisting in the chilling of the metal poured into the mold. The downward movement of the ram exerts a tractive effort on the strip for holding it in proper position between the hardened upper surface of the ingot and the guide rolls 30, and serving to draw the strip 20 from the supply reel, wherewith the brakes 23 and 24 are effective to determine the tension upon the strip, this tension being less than that later used, as described herein, to remove the core from the ingot.

When a number of core strips are being fed for providing a plurality of longitudinal channels in the ingot, and when the cores are located close to mold walls, vibrating devices 19 can be provided to act on the core strip itself, or on the tundish 13, or both. Such vibrators can be energized electrically by a 60 cycle current, to give a vibration amplitude of about 0.001 inch. This vibration assures liquid ingot metal flowing into the small spaces between cores, or between a core and the mold wall, whereby to eliminate voids in such parts of the horizontal section of the ingot; and also minimizes gas bubble formation and loss of molten metal during the casting, particularly by preventing such bubbles sticking on the core strip as it descends and becomes covered with the solidifying metal.

The ingot metal and the cores rapidly assume the same temperature, usually with significant cooling and stiffening of the molten metal at the interface. The metal and cores are in dimensional equilibrium when the poured metal has passed from the liquid to the solid state. Upon further cooling, the steel contracts at about half the rate of the aluminum; but down to about 800 degrees F., the aluminum is soft and plastically deforms without producing a binding stress upon the core strips. As the aluminum passes below about 800 degrees F., its greater contraction is not accompanied by such deformation, and an elastic hoop stress is exerted by the aluminum upon the steel, with a strain amounting to about 0.002 inch per inch of steel. Therewith, as set out hereafter after FIGURE 10, a tension load of about 30,000 pounds upon a stainless steel core having a section of 4 inches by ½ inch, equivalent to a stress of 60,000 p.s.i., with a total strain of about 15 percent, is effective to deform the core plastically so that it may be easily removed from the ingot.

The invention can also be employed with static casting of ingots. In FIGURES 3–5, the static mold 32 has devices at its top and bottom to clamp and maintain the core strips 20. In FIGURE 3, the core strip is guided and clamped by a device 33 shown in detail in FIGURES 3A to 5. One or more core strips 20 can be used, and two are illustrated in FIGURE 3. Notches 35 of the circular horizontal form and with flat bottoms are provided in the top surface of the mold, to receive the like-shaped ends 36, FIGURE 4, of a first block 34 which has downwardly convergent tapered portions 37, FIGURE 4, at the face away from the strip position. At the strip-receiving face, the first block 34 has raised portions 38 which are spaced apart by distances equal to the widths of the respective strips 20, noting that these strips may be of the same or different widths: preferably these portions 38 extend from the surfaces 39 of the strip-receiving notches between them by distances less than the thickness of the respective strip. A second block 40 has a face 41a for engaging the strips 20 and clamping them against the surfaces 39; and at its ends has hook portions 41 with tapered inner faces 42 which conform to and wedgingly receive the tapered portions 37 of the block 34, FIGURES 5 and 6. It will be noted that the block 34 is located and maintained in a predetermined position at the upper end of the mold 32 by the engagement of its end portions 36 in the mold notches 35, so that the surfaces 39 are likewise exactly located in relation to the walls 43, 44 of the mold 32, FIGURE 3; and the raised portions 38 serve for exactly locating the core strips 20 with respect to one another and to the mold walls 45, 46. At the top of the mold, sprue openings 32a may be provided: and the mold body may be in two parts as shown, for simple removal of the ingot.

It will be noted that the end of the mold can be flush with the upper surfaces of the block 34, FIGURE 3. The lower end of the mold 32 can be correctly formed and provided with clamp blocks, and then sealed by a plate 32b, of which a portion is shown in FIGURE 3, with closely fitting holes for the ends of the cores 20. The horizontal dimension of the notches 35 is shown as proper to receive end portions of the block. The floors of these notches support springs 47 located in cavities in the ends 36 of the block 34 and effective to exert a lifting effect on the clamp assembly and thereby provide a tension upon the core pieces and permit the same
to expand longitudinally while being heated by the incoming metal.

The system of FIGURES 1 and 2 is useful when the core strips are of material and thickness such that they can be flexed. For example, steel core strips up to ½ inch thickness can be so handled. When greater core sizes and stiff cores are to be used, it is provided to handle the core strips as flat plates or bars, as shown in FIGURES 6 to 8, wherewith cores of ½ inch thickness or greater may be employed.

In FIGURES 6 to 8, the mold 12 with its tundish 13, platform 14, ram 15, and other casting parts are as in FIGURE 1. It can be about 0.2 to 0.3 percent thinner and narrower than the portion within the ingot, for an elastically removable core, so that with a core 4 inches wide, it is about 0.008 inch narrow; and with a permanently deformable or stressed core of steel in an aluminum ingot, where the elastic compression of the cooled aluminum upon a steel core is involved, the lower reduced portion can be about 3.993 inches, or 0.007 inch narrower, when the core portion within the aluminum ingot is 4.000 inches wide. Corresponding thickness reductions are used. A traction device 82 is connected to the upper end of the core 80, and a second traction device 83 of lesser section than the core 84 is connected to the lower end. Upon relative separating movement of the traction devices 82, 83, e.g., by exerting forces as shown by the arrows, the core 84 is reduced in section, so that the ingot 17 can be slid from the core 80 onto the traction stem 83, to the position shown by dotted lines. This reduced stem 83 has a length greater than that of the ingot 17. Thereafter, the device 83 is separated from the core 80 and then itself withdrawn from the ingot 17.

The material for the cores 28, 60, 80 is selected according to the metal which will form the ingot; in general, it should have the properties:

1. Its melting point should be above the temperature at which the molten ingot metal enters the mold, but noting as examples that heat resistant alloys, such as those commercially available under the trademarks Hastelloy, Stellite, and Inconel may be employed while casting stainless steel, by providing a coating to restrict the heat conduction from the molten metal to the core, so that the originally cold core is not raised to fusion temperature;

2. It preferably has a reaction-protecting casing of an adherent refractory such as lime, alumina refractory, or the like, which itself is resistant to the molten metal;

3. It should be capable of accurate and firm fixation and maintenance at a predetermined location relative to the mold walls, so that the cores will be at accurate pre-selected locations relative to one another and to the ingot surface.

4. It should be resistant to a sufficient tensile load so that it can be held straight and in correct relative position even during the thermal expansion incidental to contact by the molten metal, noting that such expansion may be uneven as a result of irregularity of contact, flow and cooling of the molten metal;

5. It must be sufficiently strong to withstand handling, any necessary bending, and the tensioning effects during preparation and casting, and the forces for removing it from the cast ingot;

6. It should be capable of easy gripping and removal from the mold; and preferably having a high strain hardening so that uniform reduction occurs without necking and fracture.

Many metals respond to these requirements and may be selected according to the ingot to be made. For ex-
samples, mild steel may be employed for ingots of aluminum, copper, and other relatively low-melting metals, stainless steel for copper alloy ingots, titanium for steel ingots. It is preferable, where possible, to employ a metal for the core which has a greater rate of shrinkage, by thermal contraction, than the solidified ingot metal.

The metal can also be selected for the yield strength which it will exhibit during the removal operation. With a mild steel for example, of low yield point, the core material may be stressed, as described for FIGURE 10, beyond its elastic limit, so that the reduction of cross-section is permanent. In such cases, the end portions of a core, which are gripped by the tension jaws, are not significantly changed in section; and hence after the core has been stretched permanently and while the tension forces are still applied, a notch can be cut in the reduced section of the material at either end of the ingot and the forces continued until the core breaks at the notch region and can be withdrawn from the ingot. With a stronger steel, the stress may be kept below the elastic limit while reducing the section by the opposed pulls at its ends, and the core removed from the ingot while under such limited stress, noting that the pulling bar 63 onto which the ingot is slid during removal is smaller, feeding into the channel; and therewith when the stress is removed, the metal core returns to its original shape and size and may be re-used in a subsequent casting operation after restoring its coating of ceramic refractory. For example, such cold aluminum ingots may be molded in materials which retain their elastic properties after subjecting to the temperature of the molten aluminum: the so-called "super-alloy" steels have this behavior.

The coating spray is preferably of a ceramic material, that is, one which deposits a component which adheres firmly to the core metal and therewith resists erosion by the molten ingot metal; and serves to prevent contact of the molten metal with the core metal, as well as providing a fragile spacer layer between the metals when the ingot has cooled. Suitable materials are lime, alumina, silica, titania, talc, which can be made into a sprayable slurry with a binding substance such as water, and preferably with a volatile vehicle such as water or alcohol.

It is obvious that the illustrative forms are not restrictive and that the invention can be practiced in many ways within the scope of the appended claims.

What is claimed is:
1. The method of forming an ingot having a longitudinal hole therein, which comprises pouring metal into a mold having a solid metal core member located therein, the solid metal core member having the shape and cross-section intended for the ingot channel and extending into the mold bottom wall so that the lower part of said core member is not covered by molten metal, terminating the pouring before the upper end of the core member is covered by molten metal, cooling the molten metal to form an ingot having the core member therein with its ends accessible, engaging said ends and exerting tension along the core member to reduce its cross-section, and removing the core member from the ingot while the cross-section of the core member is less than that of the hole formed thereby in the ingot.

2. The method as in claim 1 for cyclic production of such ingots, in which the core member has a significant elastic reduction of cross-section under tension and is stressed within the ingot at less than its elastic limit for reducing its cross-section, the core member is removed from the ingot while so stressed, the core member is thereafter permitted to return to its original cross-section and is employed as before for the production of another ingot.

3. A mold for casting ingots with inserts therein, comprising mold walls surrounding the ingot space, a first clamp block extending across the space and means for moving the block away from the mold space, means on the mold walls for guiding the first clamp block during movement thereof, said first clamp block having parts for locating an ingot insert piece engaged therewith, a second clamp block for holding the insert against the first clamp block, and means for holding the clamp blocks together.

4. A mold as in claim 3, in which the first clamp block has a beveled surface opposite the place of engagement with the insert, to provide a downwardly convergent section, and the second block has a projecting hook with a conforming tapered surface, whereby upward movement of the second block relative to the first causes a relative wedging thereof and therewith a binding of the insert between the blocks.

5. A mold as in claim 3, in which multiple inserts are to be located in a single ingot, in which the clamp blocks include ribs for positioning between adjacent inserts and thereby fixing the spacing therebetween and the spacing from mold walls.

6. The method of preparing an ingot having a longitudinal internal discontinuity of predetermined size and location therein, which comprises preparing a flexible core strip of solid metal of the cross-section intended for the ingot channel, said strip having a surface to which the molten ingot metal will not bond, feeding into an opened mold, initially closing the bottom of the mold by a downwardly retractable platform, passing the lower end of the strip into the platform and securing it thereto so the lower end is protected from the poured metal, casting ingot metal into the mold and around the strip, cooling the ingot metal at the lower end of the mold to maintain closure of the lower end of the mold, retracting the platform downwardly at a rate concurrent with the continued feeding of the molten metal and therewith causing the strip to move downwardly through the mold, while the ingot metal forms and becomes solid therearound during the said retraction, maintaining the concurrence of the rates of retraction and ingot metal feeding so that a solid ingot emerges from the lower end of the mold with the strip capped therein at the predetermined location, terminating the casting while an upper end of the strip is above the poured metal in the mold, thereafter engaging the parts of the strip projecting from the cooled ingot and exerting a major tension tending to reduce the cross-section of the strip, and removing the strip from the ingot while the cross-section of the strip is thus reduced.

7. The method of preparing an ingot having a longitudinal channel of predetermined size and location, which comprises preparing a flexible ductile solid metal core strip of the cross-section intended for the channel, feeding the coated strip downwardly into an open-ended mold, applying a ceramic refractory anti-welding coating to the projecting end of the strip before it enters the mold, initially closing the bottom of the mold by a downwardly retractable platform, securing the end of the strip in the platform so that a part of the strip will protect downward from the ingot being formed, pouring ingot metal into the mold and around the strip, the ingot metal being concurrently poured into the mold at a multiplicity of points with the amount delivered at each side of the strip being equalized whereby to produce like heating and pressure effects at the external surfaces of the strip, cooling and thereby solidifying the initially poured ingot metal to maintain closure of the lower end of the mold with the strip projecting from the solidified metal, retracting the platform downwardly at a rate concurrent with the continued feeding of the metal and therewith causing the strip to move downwardly through the mold while the ingot metal forms and becomes solid therearound during the said retraction, maintaining the concurrence of the rates of retraction and ingot metal feeding so that a solid ingot emerges from the lower end of the mold with the strip capped therein at the predetermined location, terminating the casting while an upper end of the strip is above the poured metal in the mold, thereafter engaging the parts of the strip projecting from the cooled ingot and exerting a major tension tending to reduce the cross-section of the strip, and removing the strip from the ingot while the cross-section of the strip is thus reduced.
channel surfaces of the ingot, and removing the strip from the ingot while its cross-section is so reduced.

8. An apparatus for making ingots having removable core inserts therein, comprising means for supplying a flexible metal core strip, guide means for controlling the lateral position of the strip during a downward travel thereof, an open-ended casting mold for surrounding the strip at a part of its downward travel, means positioned above the mold for applying an anti-welding coating to the surfaces of the strip, a platform for initially closing the bottom of the molds, means for securing the lower end of the strip to the platform, means for retracting the platform downwardly, means for supplying molten ingot metal into the mold, and around the tensioned strip, and means for cooling the ingot metal whereby to cause it to solidify before leaving the mold incidentally to the downward travel of the platform, said applying means including a device for applying an anti-welding coating in a liquid, and a baster for evaporating the liquid before the strip comes in contact with molten metal in the mold.

9. The method of cyclically forming ingots having longitudinal channels therein of predetermined size and location, which comprises preparing a core of solid metal having a significant essentially uniform elastic reduction of cross-section under major tension, said core having throughout the part of the length thereof which is to be within the ingot the cross-section intended for the channel, positioning the core accurately in an ingot mold at the location intended for the channel with the core extending out of the mold space at its ends, exerting forces upon the ends of the core for maintaining the same under minor lengthwise tension for holding the same straight and in position during the casting of metal therearound, pouring metal into the mold and around the core member, the core extending into the mold bottom wall so that a part of said core member is not covered by molten metal, terminating the pouring before the upper end of the core member is covered by molten metal, cooling the molten metal to form an ingot having the core member therein with its ends accessible, engaging said ends and exerting major tension along the core member to elastically reduce its cross-section, removing the core member from the ingot while the cross-section of the core member is less than that of the channel formed thereby in the ingot, and again positioning the core in an ingot mold for the casting of a second ingot.

10. An apparatus for making ingots having removable internal core inserts therein, comprising means for supplying a flexible metal core strip, an open-ended casting mold for surrounding the strip at a part of its downward travel, guide means above the mold for controlling the lateral position of the strip during a downward travel thereof, a device for straightening the strip before it enters the top of the mold, means positioned above the mold for applying an anti-welding coating to the surfaces of the strip, a member for initially closing the bottom of the mold and means for controlling downward movement of the member, means for securing the lower end of the strip within the said closing member so the said lower end is protected from poured metal and the ingot is formed with the lower end of the core strip projecting therefrom, and devices for retarding the downward movement of the strip into the mold and thereby cooperative with the guide means for maintaining the strip in position preliminary to its espauling in solidified ingot metal.

11. An apparatus as in claim 10, including means for supplying a plurality of flexible metal strips, in which the said guide means includes a pair of rolls located above the mold and aligned with the position to be occupied therein by the strip, one of said rolls having projecting peripheral ribs to engage respectively the edges of adjacent strips and thereby locate the strips when entering the mold for maintaining the said strips at laterally spaced intervals in the mold, the other of said rolls having peripheral recesses to receive the said ribs, the said rolls between the respective ribs and grooves having portions for engaging the strips at opposite sides thereof, said coating means being effective for applying anti-welding material to the surfaces of each strip, and in which the said retarding means are effective upon the rolls for retarding the rotation thereof during a tension pull upon the strip incidental to downward movement of said closing member.

References Cited in the file of this patent

UNITED STATES PATENTS

29,276 Holmes July 24, 1860
29,007,301 Lemieux July 9, 1935
2,128,942 Hudson Sept. 6, 1938
2,128,943 Hudson Sept. 6, 1938
2,161,116 White June 6, 1939
2,284,503 Williams May 26, 1942
2,692,411 Brennan Oct. 26, 1951
2,907,084 Wood Oct. 6, 1959