Dec. 31, 1963 R. M. BRICK ETAL 3,116,121

INGOT AND THE MOLD AND CORE STRUCTURE FOR CASTING THE SAME

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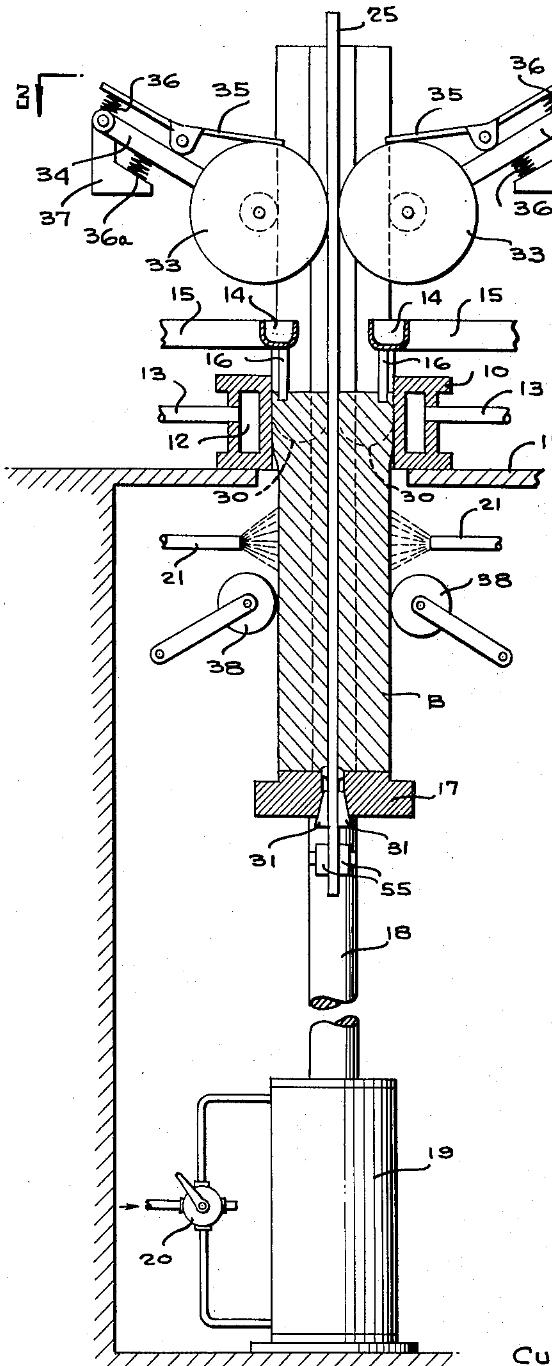

FIG. 1

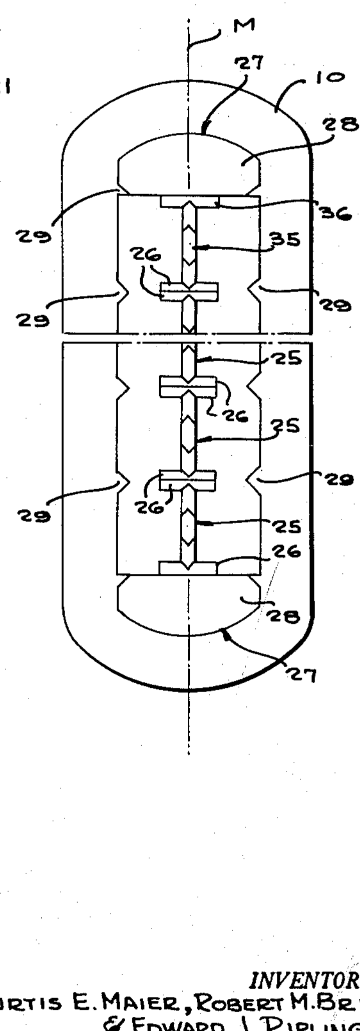

FIG. 2

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ATTORNEYS

FIG. 3

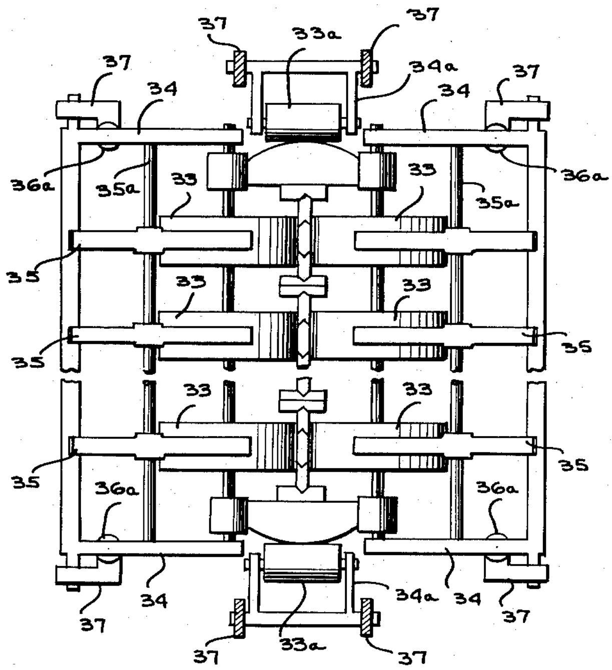

FIG. 4

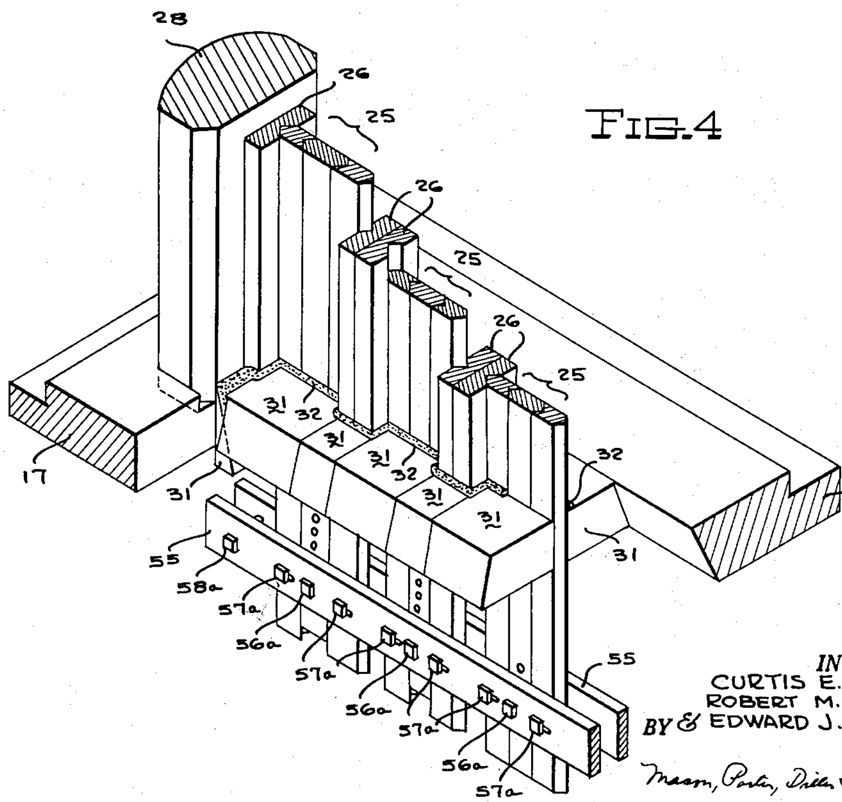

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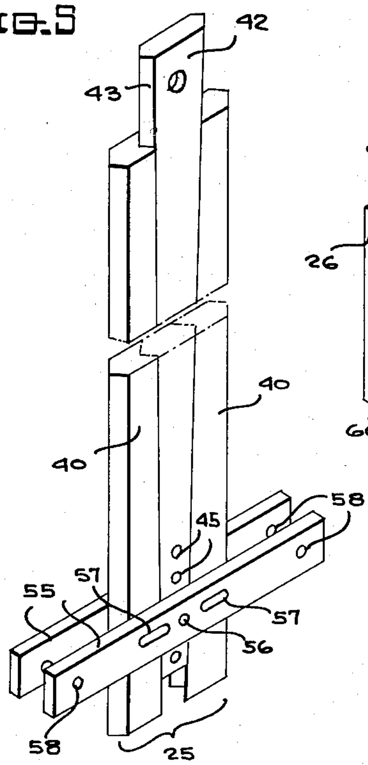
FIG. 5



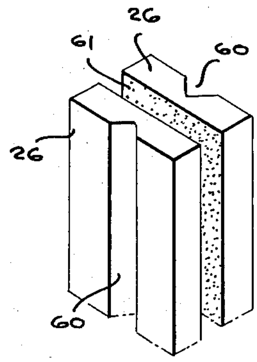


FIG. 9

FIG. 6

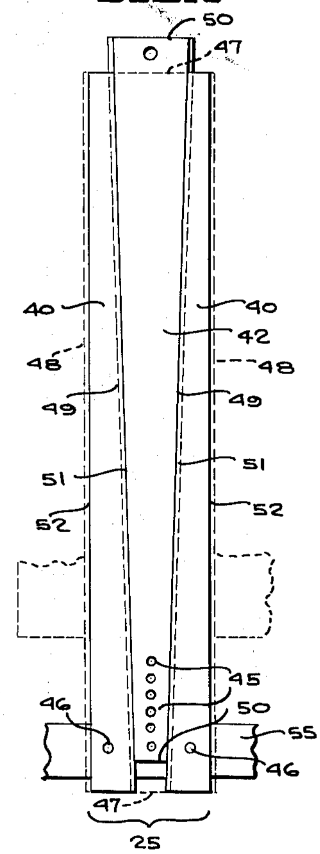


FIG. 7

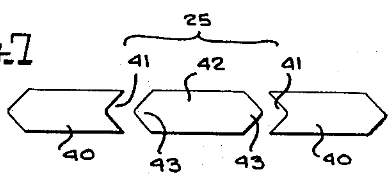


FIG. 8

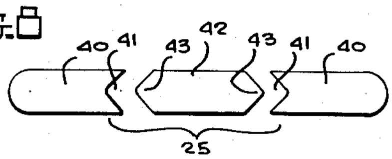


FIG. 11

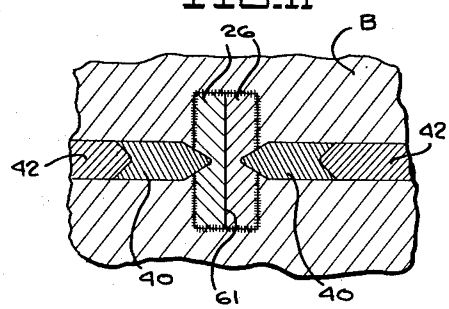


FIG. 10

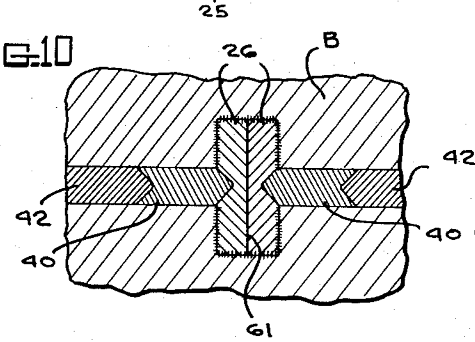


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FIG. 12

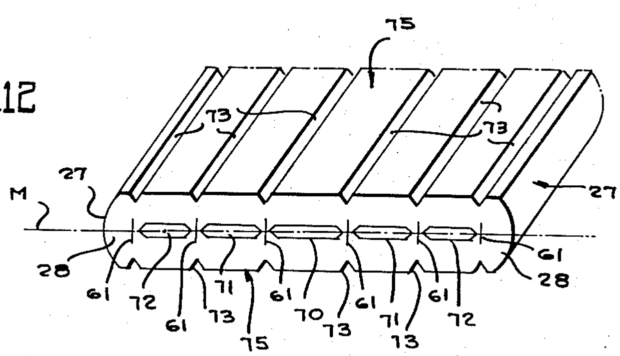


FIG. 13

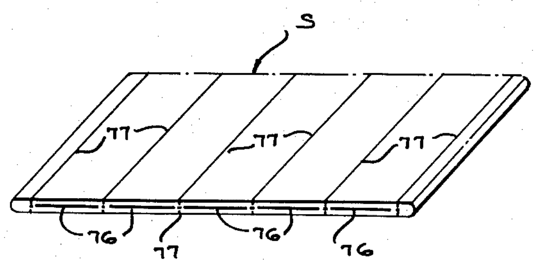
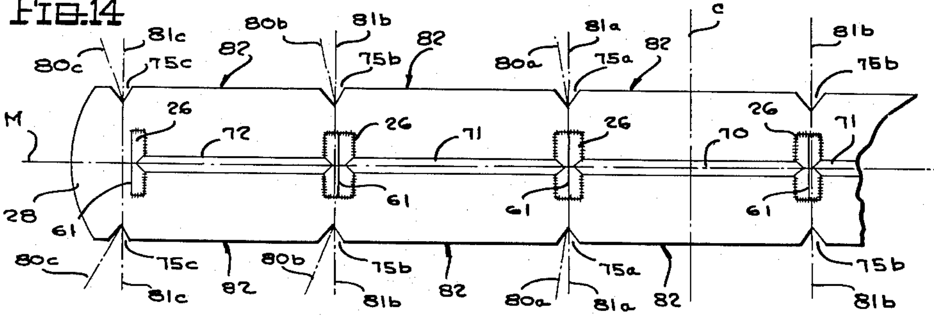


FIG. 14



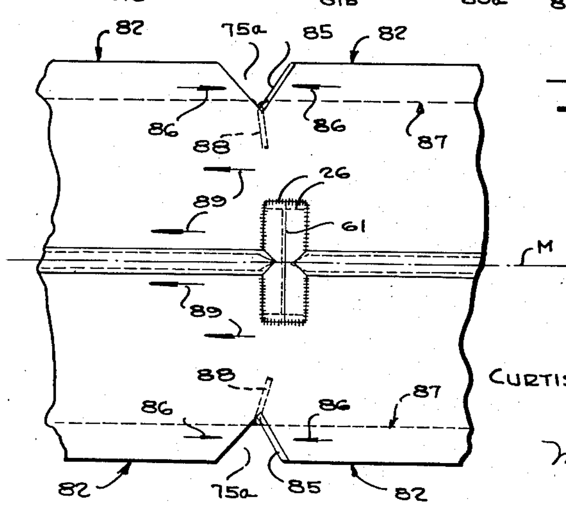


FIG. 15

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FIG. 16

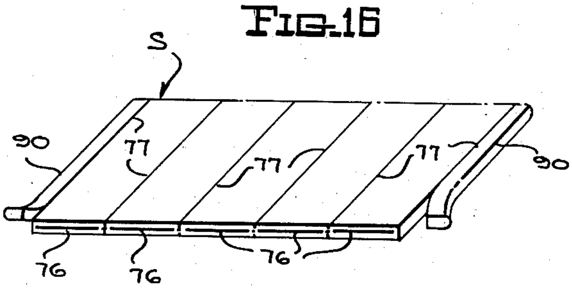


FIG. 17

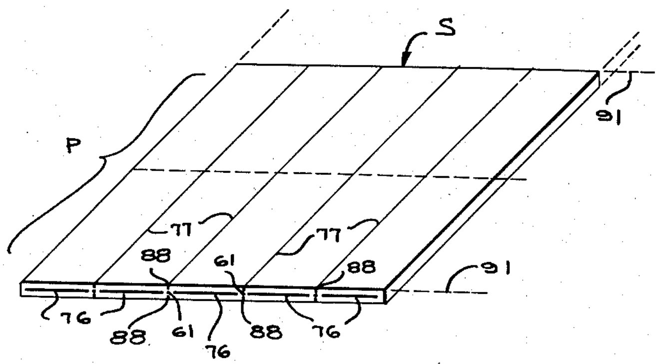


FIG. 18

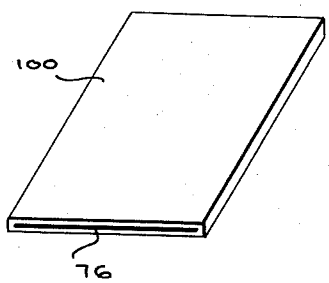


FIG. 19

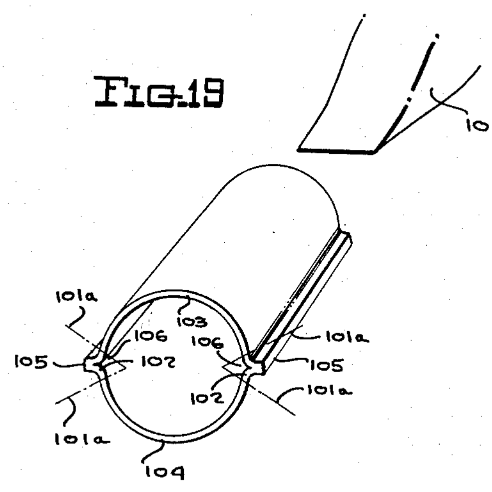
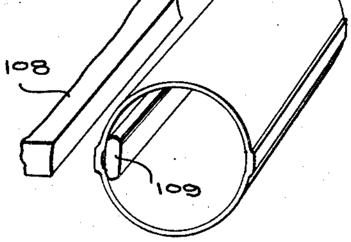


FIG. 20



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United States Patent Office

3,116,121

Patented Dec. 31, 1963

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INGOT AND THE MOLD AND CORE STRUCTURE FOR CASTING THE SAME

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Filed June 20, 1960, Ser. No. 37,266
7 Claims. (Cl. 29—187)

This invention relates to the art of preparing hollow ingots and laminate stock, and is particularly concerned with ingots and stock having longitudinal channels of closely defined cross-sections.

It is known to prepare ingots having one or more such channels, and to reduce the thickness while extending the surface area, to form a laminate stock having a like number of discontinuities therein, and thereafter to open or expand the stock by moving the laminations apart to form a tubular body with side walls comprised of the laminations and of integrating metal connecting the laminations at their longitudinal edges.

When the tubular body must have closely controlled internal cross-section, and the thickness-reduction and a length-extension is being effected by rolling, there is a lateral spreading which varies predictably with the metal, the rolling schedule of temperature and degree of reduction at each pass, and with the ingot shape. When hollow ingots are thus rolled, the lateral spreading is not uniform for each unit of width, nor for each unit of thickness: for example, with a multi-channel ingot of rectangular section and plane surfaces, the lateral spreading of a channel adjacent a lateral edge is greater than that for a channel nearer the center of width. Therewith, for economy, it is desirable to provide the channel or channels during the casting of the ingot, and to have such channels originally of a size which can produce the desired channel width in the laminate stock and the desired cross-section in the opened tubular body.

An object of this invention is an apparatus for making hollow ingots, by which the dimensions of the channels can be closely controlled, by a procedure of providing therein original channels of sizes proper under the reduction schedule to establish the predetermined final widths of the channels.

Another object is an apparatus for forming hollow ingots by employment of removable cores comprising relatively movable parts, whereby the channel dimensions can be pre-set, and whereby the cores can be easily removed from the ingots without damage thereto.

Another object is an apparatus for casting hollow ingots in a mold of limited size, from which the ingot being formed is withdrawn as portions thereof cool to the solid state, and with cores which travel through the mold with the molten and later-solidified metal, and including the withdrawal of the cores from the solidified ingots without damage thereto.

A further object is the preparation of hollow ingots having longitudinal edge and internal portions of metal softer than the cast ingot metal portions, and with longitudinal channels of predetermined dimensions in the central portions.

With these and other objects in view, as will appear in the course of the following description and claims, illustrative embodiments of the invention are shown in the accompanying drawings, in which:

FIGURE 1 is a conventionalized upright sectional view of a so-called direct-chill casting apparatus showing a practice under the invention;

FIGURE 2 is an end view of an ingot being cast in the mold, with cores and other parts in place;

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FIGURE 3 is a horizontal view, essentially on line 3—3 of FIGURE 1;

FIGURE 4 is a perspective view of part of the mold platform, with parts of cores and other elements thereon;

FIGURE 5 is a perspective view of a core structure;

FIGURE 6 is an elevation of parts of a core structure, with the angle of taper exaggerated;

FIGURE 7 is an end view, showing the relationship of the parts of a core member having chisel-shaped edges;

FIGURE 8 is a corresponding view of a core member having rounded edges;

FIGURE 9 is a perspective view of a pair of spacer members;

FIGURES 10 and 11 show engagements of core members with spacers;

FIGURE 12 is a perspective view of part of an ingot made according to this invention;

FIGURE 13 is a perspective view of a part of a strip made by rolling the ingot of FIGURE 12;

FIGURE 14 is an end view of part of the ingot of FIGURE 12, on a larger scale;

FIGURE 15 is an end view of part of the same ingot, on a still larger scale;

FIGURE 16 is a perspective view showing detachment of the edges of the strip of FIGURE 13;

FIGURE 17 is a perspective view of a section cut from the strip of FIGURE 16;

FIGURE 18 is a perspective view of a single blank;

FIGURE 19 is a perspective view of the same after opening;

FIGURE 20 is a perspective view of the opened blank, showing the conformation of the projecting fins of FIGURE 19.

In FIGURE 1, conventionalized parts are shown, including an ingot casting mold **10** mounted on a deck or floor **11**, above a pit into which the ingot is lowered during the course of its formation. The mold has a peripheral cooling chamber **12**, with ducts **13** for supply and removal of cooling fluid. A tundish structure **14**, served by supply troughs **15**, has the valved drop tubes **16** by which molten metal is delivered into the casting mold. At the start of a casting operation, the lower end of the mold **10** is closed by a platform **17** connected to a piston ram structure **18** which can be raised and lowered by a cylinder **19** accordingly as the delivery or removal of pressure fluid to its ends is controlled by the valve **20**. The descending ingot B can be cooled by water jets from the nozzles **21**.

According to this invention, one or more composite removable cores **25**, FIGURES 1 to 4, are fixed and sealed in the platform **17** before the start of the metal pouring, and extend upwardly through the mold and between parts of the tundish structure **14**. In a preferred form of practice, FIGURE 2, the individual core structures **25**, of which four are shown, are located essentially at the median plane M between the ingot surfaces which are to be brought into reduction contact with the rolls: and pairs of abutting spacer members **26** are positioned between each two adjacent core structures, with a single spacer member at the lateral edges of the outermost core structures. The lateral margins **27** of the ingot need not be cast with the central portion thereof, but may be provided by pre-formed edge pieces **28** which are originally connected to the platform **17** and travel downward with the ingot. Such edge pieces **28** can have a cross-section of 1 to 2 inches along the median plane M, FIGURE 2, for ingots 28 to 36 inches wide and 6 or 8 inches thick, dependent upon the metal being cast and the rolling schedule; and corresponding thickness for other ingot dimensions. The mold **10** can have inwardly projecting ribs **29** which produce corresponding longitudinal grooves in the ingot, noting that pairs of such ribs can be employed for guiding and aligning the edge pieces **28** during their descent.

The core structures, spacers and edge pieces are assembled and attached to the platform **17** as shown in FIGURE 4. For this, the platform has an aperture and the core structures extend through the platform, so that cleats **55** can be positioned below the platform wherewith only parts of each core structure having flat surfaces are located within the ingot, with the wider surfaces parallel to one another and providing continuous areas for defining the wider channel surfaces in the ingot. Spacers **26** can be received also in the platform aperture. Normally, the edge pieces **28** are heavier, and can descend in the mold by their own weights, or by the downward pulls exerted upon the solidified ingot from the cores and spacers: pockets for aligning them may be provided in the platform, as in FIGURE 4. The core structures and spacers can be held by wedges **31** driven upward between a platform aperture wall and the structure or spacer. The end pieces **28** may be likewise secured. The platform aperture may be made large enough for the widest spacers **26**, when ingots are to be made of differing dimensions with the single platform **17**: wherewith different numbers of spacers and cores can be assembled thereto, with wedges **31** of appropriate size to essentially fill the gaps. Fire clay packing **32** can be employed to fill any crevices.

The assembly can be guided and held, above the mold, as conventionally shown in FIGURES 1 and 3. Rollers **33** engage the opposite faces of the core structures and end pieces and hold them in alignment, being rotatable on shafts carried by the rocker brackets **34** and having brakes **35** pivoted on shafts **35***a* which restrict the rotation of the rollers, so that a low tension is exerted along the core structures as the platform sinks: the brakes may be held engaged by springs **36**. The rocker brackets **34** are held engaged with the cores and end pieces by strong springs **36***a* which permit minor movements under the forces exerted by thermal expansion of the cores and end pieces. End guides comprising rollers **33***a* on spring-pressed rocker frames **34***a* act against the end pieces in the plane of the cores **25**, and press them toward one another so that these end pieces, the cores and the spacers **26** are held in abutment and accurately guided for downward movement. The rocker frames **34**, **34***a* are pivoted in fixed supports **37**. Driven rollers **38** are preferably employed below the mold, for engaging the ingot B and exerting a downward effort upon it.

With the platform raised to close the mold bottom, and with the core structures **25**, the spacers **26**, and the edge pieces **28** sealed in place thereon, the pouring of metal is begun. This metal solidifies within the mold and upon the platform, and the level rises to near the top of the mold, by control of the metal pouring as known in the art. The rollers **38** are driven and valve **20** is operated, so that the platform descends with the solidified lower part of the ingot B thereon. The pouring of metal and the descent of the platform are coordinated so that the level of molten metal is kept essentially constant. In practice, the metal solidifies as a film adjacent the cooled walls of the mold and against the core and other descending structures so that the zonal interface between the liquid and the solidified ingot metal has a form as indicated by the lines **30**, **30** in FIGURE 1. Therewith, the molten ingot metal bonds or welds to the exposed surfaces of the spacers **26** and to the end pieces **28**: but does not bond to the core structures nor enter between the core members or between the spacers **26**. In solidifying and cooling, the ingot metal, with the end pieces **28** and spacers **26** integrated therewith, contracts and normally is free of the mold **10** at the lower end thereof. When an ingot of the desired length has been formed, the platform **17** and the metal pouring are stopped: the molten metal is allowed to solidify, the ingot is withdrawn, new spacer and end pieces are introduced and the same or other cores positioned, and the pouring

of a new ingot begun with the platform **17** again raised into sealing position.

The core structures **25** can be formed as in FIGURES 5, 6 and 7. The side members **40** can have linear longitudinal outer edges of rounded form, FIGURE 8, but preferably are of chisel-shaped cross-section, FIGURE 7, formed by convergent surfaces leading to the extreme edges which can be blunted by a merging curvature of radius much smaller than the thickness of the core; e.g., with a core thickness of 0.125 inch, the included angle at the chisel edge may be 10 to 90 degrees, and the edge radius about $\frac{1}{64}$ inch. In practice, angles of 14 degrees and 28 degrees have been found to yield essentially identical results. Angles of 10 to 60 degrees are preferred for aluminum. The members **40** have inner edges which converge longitudinally, FIGURE 6, for the pair of members, toward one end, e.g., the lower end in the drawings. These inner edges have keyways **41** illustrated as grooves of essentially triangular section with a 90 degree root angle. The central member **42** has its edges of mating convergent form, with a triangular sectional shape for each which corresponds to the keyways **41** and provides a key **43** accurately fitting the keyway walls. Illustratively, for ingots up to 14 feet in length, each core member can be 16 feet long; the lateral members **40** can be about 2 inches wide at one end and $1\frac{1}{2}$ inches at the other: the central member **42** can be one inch wide at one end and two inches wide at the other: therewith, when the ends of the members are aligned, the over-all width is 5 inches at each end and along the entire length. Similarly, when a core width of, say, 6.12 inches is desired, the center member can likewise be one inch wide at the lower end, and two inches wide at the upper end, and the side members can have dimensions of 2.66 inches at the lower ends and 2.06 inches at the upper ends, for the same angle of taper. Obviously, other coordinated dimensions can be selected, dependent upon the chosen taper angle and the desired core width.

Such chisel shapes facilitate the accurate assembly of the parts preliminary to pouring; and have a primary advantage in producing a cross-sectional shape of channel for receiving a liquefiable resist and wherewith the channel section changes during the early rolling passes without producing wrinkles or "orange peel" appearance of the surfaces of such channels during the time of bringing the opposed inner surfaces toward one another with a thin film of liquid resist between them.

The depth of the groove **60** in the spacer **26**, FIGURE 9, determines the overlap of the spacer metal onto the channel or discontinuity form by the core assembly **25**; and thus onto the resist or antiwelding material later introduced into such channel, and ultimately the overlap of the spacer metal at the edge of the resist residue in the rolled strip. In practice with liquefiable resists, the groove can be, for example, $\frac{1}{16}$ inch deep with spacers 0.125 inch thick. Thus, FIGURE 10, when the core pieces **40**, **42** are 0.125 inch thick, and the included edge angle is 90 degrees, the angular edges fill the grooves. In FIGURE 11, where the included angle is 30 degrees and the core pieces are also illustratively 0.125 inch thick, with the spacers **26** having a like thickness and grooves for half this thickness, only parts of the angular edges are received in the respective grooves. In FIGURES 10 and 11, the weld-bonding of the cast metal of the ingot B to the spacers **26** is indicated by the short hatching lines at the interfaces: and the non-welding to the cores is shown by the absence of such hatching.

Such core members are made with surfaces of material to which the molten ingot metal will not bond. For example, for ingots poured from aluminum or aluminum alloy, the bodies can be made of steel and given approximate shaping by machining. The keys and keyways are then accurately ground so that the abutment wall surfaces are plane and smoothly finished, e.g., to 10 microinches. These surfaces can be given a hard chromium plating.

The three members of a core structure are loosely assembled with the keys and keyways engaged with one another, and then clamped into tight abutment: they are then surface-ground at the two sides to obtain the desired thickness and to assure that such sides will form planes while in service. These surfaces can also be given chrome plating, due allowance therefor being made during the surface grinding. For example, each of the three members can be made 0.150 inch thick by machining and during the formation of the keys and keyways; and then ground to 0.125 inch thick while clamped together.

For the purpose of relative longitudinal location and securing of the core members, the central member **42** is illustratively shown, FIGURE 6, as having a number of holes **45** spaced along its center of width; and the side members **40** have holes **46**. Before assembly, it is preferred to apply a lubricant for action between the key and keyway surfaces, which will be effective after the heating by the ingot metal. For example, the walls of the keyways **41** may be thinly coated with molybdenum disulfide. The core members are assembled by bringing them tightly together with the keys in the keyways, and adjusting their relative longitudinal position to obtain the desired width. Thus, with the above dimensions, the core structure **25** will have a width of 5 or 6.12 inches when the ends are aligned as shown by the dash lines **47** in FIGURE 6 with the core width indicated by the dash lines **48** and the core member abutments by the dash lines **49**; noting that the angularity and spacing have been exaggerated in FIGURE 6 for clearness. Upon shifting the central member **42**, e.g., upward in FIGURE 6 to the position shown by unbroken lines **50**, and bringing the abutment between members at the unbroken lines **51**, the over-all width between the edges of the side members **35** is at lines **52**, that is, the width has been decreased to the position shown by the dash lines **48** to that of the unbroken lines **52**. By relative movement in the opposite direction, the width of the structure can be increased. The members can then be clamped in position, e.g., by cleats **55**, FIGURES 4 and 5, which have aligned holes **56** for receiving a pin or bolt **56***a*, which passes through a selected hole **45** in the central member **42**, and slits **57** for receiving bolts **57***a* which pass through the holes **46** of the side members **40**. The cleats also may have holes **58** for clamping bolts **58***a* which pass outside the core members. With dimensions of the core members of 1 and 2.651 inches at the bottom with 2.151 and 2 inches at the top, for a core 6.102 inches wide, when the lower ends are aligned as shown at the right in FIGURE 4 a longitudinal displacement of member **42** upward from the dash line position, FIGURE 6, by one inch will give an over-all width of 6.097 inches, and a downward displacement will give a width of 6.107 inches: that is, by spacing the holes **45** one inch apart, the core structure can be varied in width by increments of 0.005 inch.

Illustratively, if a can 4.06 inches in diameter is to be made, with a rolling spread of 4 percent, the central core can be 6.122 inches wide at room temperature, and the successive lateral cores 6.102 and 6.082 inches for a five-wide billet and strip. The five core widths then total 30.490 inches. The spacers **26** can be 0.125 inch thick, with the grooves **60** extending for half the thickness, with a total metal dimension, upon assembly, of 0.625 inch. The edge pieces **28** can each be 1½ inches thick. The ingot thereby formed will have a total width, in the mold, in excess of 34 inches: and upon cooling will have the channels essentially of the differentiated widths stated above.

The spacers **26** can be made, as in FIGURE 9, of rolled, extruded or forged stock of a metal compatible with the molten ingot metal: that is, the molten ingot metal can weld or bond to surfaces thereof so that the spacer becomes integrated into the ingot. With the preferred chisel-shaped edges on the core structures, an exposed face of each spacer has a conforming longitudinal

groove **60** so that the core structures and spacers can be locked together, and are effective to provide corresponding edges on the channels or discontinuities being formed in the ingot. For aluminum or aluminum alloy poured ingot metal, the spacers **26** may be of wrought pure aluminum, which is softer than commercial aluminum alloys and is advantageous when the poured metal is harder, to provide ductility along the edges of the channels during the opening operation. Pairs of these spacers are provided between adjacent core structures, and one is provided between each outermost core structure and the adjacent edge piece **28**, as shown in FIGURE 2. Before employment, it is preferred to provide anti-welding coatings **61** on the backs or flat abutment surfaces of the spacers: such may be a light coating of soot, e.g., by a smoky acetylene flame, or a bonded dressing of refractory oxide powder, or a thin silicone coating, for aluminum ingots. Other surfaces of the spacers are preferably cleaned so that the poured metal will bond easily and strongly thereto.

After the ingot B has been removed from the mold and platform, with the core structures therein, these structures are removed. The cleats **55** and the bolts and pins therein can be removed before separating the ingot from the platform.

The small end of each center member **42** can be tapped, and the wide end pulled, so that this center member is pulled out from between the side members **40**, with its plane faces sliding along the inner surfaces of the channel in the ingot. As it leaves, the compressive strains exerted from solidification shrinkage in the direction of the median plane M are relieved, and the side members **40** can similarly be removed. Therewith, each core structure has established a channel in the ingot of a size determined by its own thickness and by the adjusted width between its longitudinal edges; with parallel wider surfaces joined by the convergent end sections.

Similar operations can be performed for ingots of other metals, with appropriate selection of materials. For copper, stainless steel can be used for the core members: for mild steels, titanium members are usable. With copper, the thin carbon films from a smoky flame can be used for the anti-welding dressings: for steel, a flame sprayed refractory such as alumina powder, is useful where carbidization is undesirable.

FIGURE 12 shows an ingot formed with cores of the type in FIGURE 7, the relative width dimensions being exaggerated for clearness. This ingot B has five core channels aligned along the median plane M of its thickness. The central channel **70** is the widest, being 6.122 inches in an illustrative example above: the next outward channels **71** are each 6.102 inches wide; and the laterally outermost channels **72** are each 6.082 inches wide.

The cast metal has bonded with the spacers and the edge or end pieces; so that only the inter-spacer anti-welding layers **61** are present at the ingot ends. The ingot can be formed with the longitudinal external grooves **73** which can be of V section and arranged in pairs at the regions of the layers **61**: such can be produced by the ribs **29**, FIGURE 2, and then dressed to the desired final size and shape; and preferably receive on one or both walls of each groove a coating of anti-welding material.

One end of such an ingot can then be closed by wedges and welding, and a liquefiable resist introduced. For aluminum ingots, suitable resist materials are organic substances such as polysiloxanes, polyvalent metal stearates such as the ferric or aluminum soaps, epoxy resins, hydrocarbon polymers such as polyethylene and polypropylene. Such organic materials have been found to endure temperatures of 900 to 1,000 degrees F. without losing ability to prevent welding of the metal when employed as set out herein. Such materials can liquefy below such temperatures but maintain the desired anti-welding property when air is excluded. The ingot can be heated for homogenization, the resist introduced, and the hot rolling begun at once so that the flow of the metal with closure of the core channel walls upon the resist quickly effects expulsion of air and prevents its re-entry: or the ingot may be brought to a temperature of 300 to 500 degrees, at which the resist liquefies, the resist introduced and the other ingot end sealed, and the ingot raised to the hot-rolling temperature.

Refractory resist materials, such as particles of alumina, zirconia, silica and silicates, talc, and graphite, in sizes of a few microns downward, can be introduced into the channels of ingots formed in the present fashion, for example, by vibrating the ingot while the powder is being introduced into the channels, and thereby attaining a substantially uniform packing with uniform density of the resist. The ingot is then raised to the hot-rolling temperature.

The ingot is then hot-rolled. During the early breakdown passes, the channel surfaces approach one another, without the formation of internal wrinkles when the channel has been formed from cores as in FIGURE 7. Thus, an ingot 8 to 12 inches thick can be reduced to a slab or billet 4 to 6 inches thick, having the longitudinal core channels therein and each filled with resist material from edge to edge and end to end. The billet can be reheated to 900 degrees, for an aluminum or aluminum alloy billet; and further hot-rolled to a hot band 0.090 to 0.150 inch thick, which can be heat-treated, and then cold-rolled to the desired final gage, e.g., 0.010 to 0.020 inch, with intermediate annealings if desired. For examples, with standard 3003 or 5052 aluminum alloys, the final intermediate annealing during cold-rolling can be performed at a thickness at which the finished strip will have the hardness desired, such as quarter-hard, half-hard, or full-hard. Some alloys can advantageously be heat-treated after cold-rolling to final gage. For example, 5052 aluminum alloy may be heated for 1 to 4 hours at 350 to 500 degrees F. to relieve stresses: and 6061 aluminum alloy may be heated for an hour at 980 degrees F. to remove work hardening effects and cause precipitation components such as magnesium silicide to re-dissolve; with quenching in cold water so that age-hardening can later occur at room temperature or be accelerated by heating to 300 to 400 degrees F. to attain the hardest temper effect. In general, the strip can be annealed and quenched as a coil: it is prefered to pass the strip through a roller-leveler after quenching, to eliminate warpage effects which have arisen.

During the course of the rolling, there is usually a lateral spreading of the ingot by ½ to 10 percent or more in width. The greater the degree of reduction per pass, the greater the spreading during such pass. The spreading with rectangular billets having resist-filled internal channels is not uniform for like units of width: in general, the channels at the center of width spread less than those closer to the lateral edges. Here, also, with greater reduction per pass, the differential spread of the channels is greater. This can be compensated by the differentiated width of the resist-filled channels, and by the presence and tilting of the longitudinal external grooves.

Further, the surfaces 75, FIGURE 12, originally in contact with the rolls, and later the upper and lower surfaces of the partly rolled billet, have essentially no lateral spread, but the spreading effect occurs between such surfaces, for example, adjacent the median plane M. This is compensated by the tilting of the grooves, and by the lateral displacement of the roots of these grooves relative to the adjacent spacer pieces.

It is desirable, when tubes of specified internal size are to be the final product, that the widths of the resist residues 76, FIGURE 13, should be the same. In practice, during rolling of a rectangular billet having originally channels 71 of the same width, the channels adjacent the longitudinal edges are wider than those at the center.

Under the practice of this invention, the channels 71 are initially of differentiated widths, so that the rolled strip S, FIGURE 13, has the resist residues 76 of the same widths by reason of the compensation due to lateral spreading, and the residues 77 of the coatings applied in the grooves 73 extend at right angles from the rolled surfaces and normally are invisible in the rolled strip, but reveal themselves when the strip is bent about longitudinal axes.

It is preferred to shape and locate the external longitudinal grooves 73 of FIGURE 12 as shown by FIGURE 14, in which one lateral half of a five-channel ingot B is shown at the left of the upright central plane C. The ingot is symmetrical about the median plane M. The spacers 26 are outlined, with hatched lines to indicate that they have become integrated into the billet. The successive external grooves *75a*, *75b*, *75c* from the central plane are shown as having successively greater tilts; that is, the bisector planes *80a*, *80b*, *80c*, have successively greater angles from the upright planes *81a*, *81b*, *81c* which pass through the roots of the respective pairs of grooves. Such grooves may have root angles of 10 to 70 degrees: the depths of the grooves, from the respective ingot surfaces 82 such that the total of the two grooves and the upright dimension of the interspacer parting material 61 does not exceed half of the total ingot thickness between the surfaces 82.

It is also preferred, noting FIGURE 14, so to locate the grooves 75 that the lateral spreading adjacent the median plane M, as compared to the usual lack of spreading at the surfaces 82 which are in contact with the rolls during rolling, is also compensated. Thus, the upright plane *81a* defined by the roots of the grooves *75a* passes laterally outside the coating 61 of the associated spacers 26 by a small distance, corresponding to the limited lateral spreading of the channel 70 during rolling: while the planes *81b* defined by the roots of the grooves *75b* and the planes *81c* defined by the roots of the grooves *75c* are at successively greater distances from the respective coatings 61. Therewith, with the selected rolling schedule, the differential lateral spreading of the core channels 70, 71, 72 during rolling brings the groove roots and the coatings 61 into alignment at the end of rolling.

Coatings 85, FIGURE 15, of anti-welding material such as a polysiloxane grease, a bonded inorganic powder, or soot, is applied to one or both walls of each groove, to prevent later welding between the wall surfaces and to establish longitudinal weakening or notching effects in the rolled strip.

The effects during rolling are illustrated in FIGURE 15. During the early rolling passes, there is a minor lateral flow of metal beneath but near the surfaces 82, so that the grooves become closed, as shown by the short arrows 86. Therewith, the ingot is reduced in thickness to establish the surfaces 87, and the anti-weld residues of coatings 85 have become films 88 extending from these surfaces: noting that the metal flow has not yet shifted the films so that the films of a pair of grooves lie in a common upright plane, but are still relatively tilted. Therewith the thickness of the channels 70, 71, 72 and the spacers 26 of FIGURE 14 are likewise reduced as shown by the dotted lines in FIGURE 15, noting that such reductions are usually not linearly proportionate to the total thickness reduction from lines 82—82 to lines 87—87. During the continuance of rolling, the metal between the inner edges of the films 88 spreads laterally away from the center plane C, and therewith the coating 61 moves outward. At the end of the rolling schedule, the films 88 have become erect, and lie in a plane which passes through the respective coating 61: and there are three weakness areas at each such plane, two being provided by the films 88 which extend from the outer surfaces, and the third by the respective coating 61. The thickness of the ingot is successively reduced by the rolling, until the strip of FIGURE 13 is produced; and therewith, the dimensions of the films 88 and coatings 61 are likewise reduced in essentially the same proportion. When the resist material in the core channels 70, 71, 72 is liquid during the hot rolling, the thicknes of these channels is reduced during the course of the rolling, usually with expulsion of some of the resist material at the initial hot-pass, so that the final thickness of the core channel resist residue may be a few ten-thousandths of an inch or less. For example, if the strip of FIGURE 13 is 0.020 inch thick, the combined dimensions of the weakenings can occupy 0.008 or 0.009 inch, and the remainder of the thickness is composed of rolled metal. The greater travel of metal, in the lateral spreading, at points nearer the median plane M than the inner edges of the films 88 is indicated by the longer arrows 89.

With ingots shaped as in FIGURES 14 and 15, during early stages of the rolling between surfaces 82, the channel 70 at the center plane C is broadened less than the lateral channels 71 and 72. The flow of metal laterally as at 86 to close the lateral grooves *75a*, *75b*, and *75c* establishes some compensation, so that this factor, combined with the differentiated widths of the channels 70, 71 and 72, has the result that with a given rolling schedule, the channels will have uniform widths at the end of rolling.

The grooves *75c* nearest the margins of the billet provide aligned residues which are at essentially uniform spacing from the edges of the residues 76 in the outermost channels 72. During the rolling, the strip may receive "camber," that is, its lateral edges are curved rather than straight lines. During the coiling of the strip when rolled to final thickness, the marginal portions 90, FIGURE 16, may be torn away, with the severance following the lines of the residues 77, so that the edges of the residual central portion of the strip now lie at essentially uniform distances from the edges of the outermost channel resist residues 76 and can be employed as reference lines in cutting the strip into sheets along lines at right angles to these reference edges, even though camber is present.

Thus, in FIGURE 17, the rolled strip S, with five channel resist residues extending along its length, may be severed at lines 91 to form panels or sections P of multi-high, multi-wide individual blanks, which can receive lithographic coating, embossing, and other treatments as multiple units. Such sheets can then be separated into individual blanks, by bending the sections about longitudinal axes, that is, axes parallel to the weakenings 77, thereby over-stressing the metal along the planes of the resist residues 88, 61, and causing the sheet to break along these planes, without intrusion of the break into the channel resist residue regions. In the original ingot of 8 to 12 inch thickness, the edges of the cores may be spaced ⅛ inch from one another: but when such an ingot is rolled to a strip 0.20 inch thick, the distance between a pair of surface resist residues 88 is far less than the spacing between the cores. Such a piece may have the length of one or more individual blanks, and it may now be trimmed and severed as desired, to provide a single blank 100, FIGURE 18.

An individual blank 100, FIGURE 18, may be opened or expanded, as by a mandrel 101, into a desired tubular section, FIGURE 19. Therewith, when a ductile metal has been employed for the spacers, the bending at the edges of the channel resist residue 76 occurs in such metal as indicated by the dotted limit lines *101a* for the portions 102 of the soft metal: and the lamination portions 103, 104 of harder metal are bent apart to curves of greater radii. Therewith, the outwardly projecting fins 105 are of soft metal, of double the thickness of the laminations 103, 104, and present re-entrant angles 106 at the inner surface. After trimming the fins, if desired, they may be reduced in distance of projection as shown in FIGURE 20 by the illustrative use of a hammer tool 108, while the expanded tube is supported internally by an anvil 109 of appropriate section, so that the inner and outer surfaces of the tube are smoothed, with essential disappearance of the re-entrant angle, as shown in FIGURE 20.

The illustrative practices are not restrictive, and the invention can be practiced in other ways within the scope of the appended claims.

What is claimed is:

1. An ingot competent of rolling to produce a laminate strip having a multiplicity of longitudinally extending non-welded internal regions of uniform width and spaced laterally from one another and from the edges of the strip, comprising a metal body having essentially parallel external surfaces to be engaged by the reduction rolls, and having between said surfaces and spaced from one another and the lateral edges of the body a multiplicity of hollow longitudinally extending internal channels located substantially in a plane, the channels having successively lesser widths from the center of width of the body toward its lateral edges whereby differential lateral spreading of the channels during rolling will bring the channels to a uniform width in producing the strip, the metal between each two adjacent channels having metallurgically a wrought structure and integratedly bonded to the cast metal structure of other parts of the ingot.

2. An ingot as in claim 1, in which the metal between each two adjacent channels is in two parts separated by a layer of anti-welding material extending across said plane and terminating in spaced relation to said parallel external surfaces.

3. A mold and core structure for casting ingots having a multiplicity of hollow internal longitudinal channels therein, said channels having differing widths, comprising a mold body having a mold cavity therein, a plurality of core structures each having side and center members with interengaging parts at their abutting edges, the center member being tapered at its said edges from end to end of its mold-received portion and the side members each having the abutting edges thereof tapered oppositely to mate with the taper of the center member, said members having mating ribs and grooves along their abutting edges and being adjustable longitudinally relative to one another, each said core structure presenting surfaces extending across the central and side members thereof for forming the surfaces of a channel in the ingot and means for holding the members in the mold cavity and in edge-abutting relation whereby the distance between the outer edges of the side members and thereby of the respective widths of the channels being formed is determined by the prevailing relative longitudinal positions of the members and the mating ribs and grooves maintain the ingot-metal exposed surfaces in alinement.

4. An apparatus for making ingots having a plurality of hollow internal longitudinal flat channels extending from end to end thereof, said channels being of controllably differing individual widths between their lateral edges, which comprises a mold member having an upright mold cavity extending therethrough, with the sides of the horizontal cross-section of the mold cavity closer together than the ends of the said cross-section of said cavity, a plurality of core structures each having abutting and inter-engaged side and center members of mating inverse edge tapers and having surfaces resistant to bonding by the molten ingot metal, said side members presenting lateral edges for forming the said lateral edges of the respective channel, said members being located in the said mold cavity in a row essentially parallel to the sides thereof and being longer than the ingot to be made so that they extend below the bottom of the ingot mold and above its top, means for closing the bottom of the mold member and having apertures through which the core structures can be introduced, holding means located below the bottom of the mold member and including individual parts for engaging and supporting the side and center

members of the core structures with the said members of each core structure in said abutting and interengaged condition at the lower end of the mold member, said parts being constructed and arranged for holding the center member of a core structure at a different height than the side members thereof so that the lateral edges of the said side members can be secured by said parts at the distance proper for the selected controlled width of the respective channel, and means located above the top of the mold member for holding the said side and center members of the core structures in said abutting and interengaged condition at the top of the mold and for maintaining a selected spacing between adjacent core structures.

5. An apparatus as in claim 4, including means for withdrawing said mold bottom closing means and said individual core member holding parts downward at a concurrent rate.

6. An apparatus as in claim 4, in which the mold bottom closing means has openings located between the said apertures for the core structures for the passage of preformed spacer pieces to be integrated into the ingot being formed, in which said holding means include parts for holding such spacer pieces between and in contact with and immovable relative to said core structures, and in which said holding means located above the mold member includes parts for holding said spacer pieces and core members in abutment with one another.

7. An apparatus as in claim 4, in which the members of each core structure are of like thickness, and in which the said holding means located above the mold member includes guides engaged with the members of each core structure to hold their engaged surfaces in parallel planes, with the core structures essentially midway between the sides of the horizontal cross-section of the mold cavity.

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