July 23, 1963 R. BAIER 3,098,269

MOLD FOR CONTINUOUS CASTING

Filed May 9. 1960 3 Sheets-Sheet 1

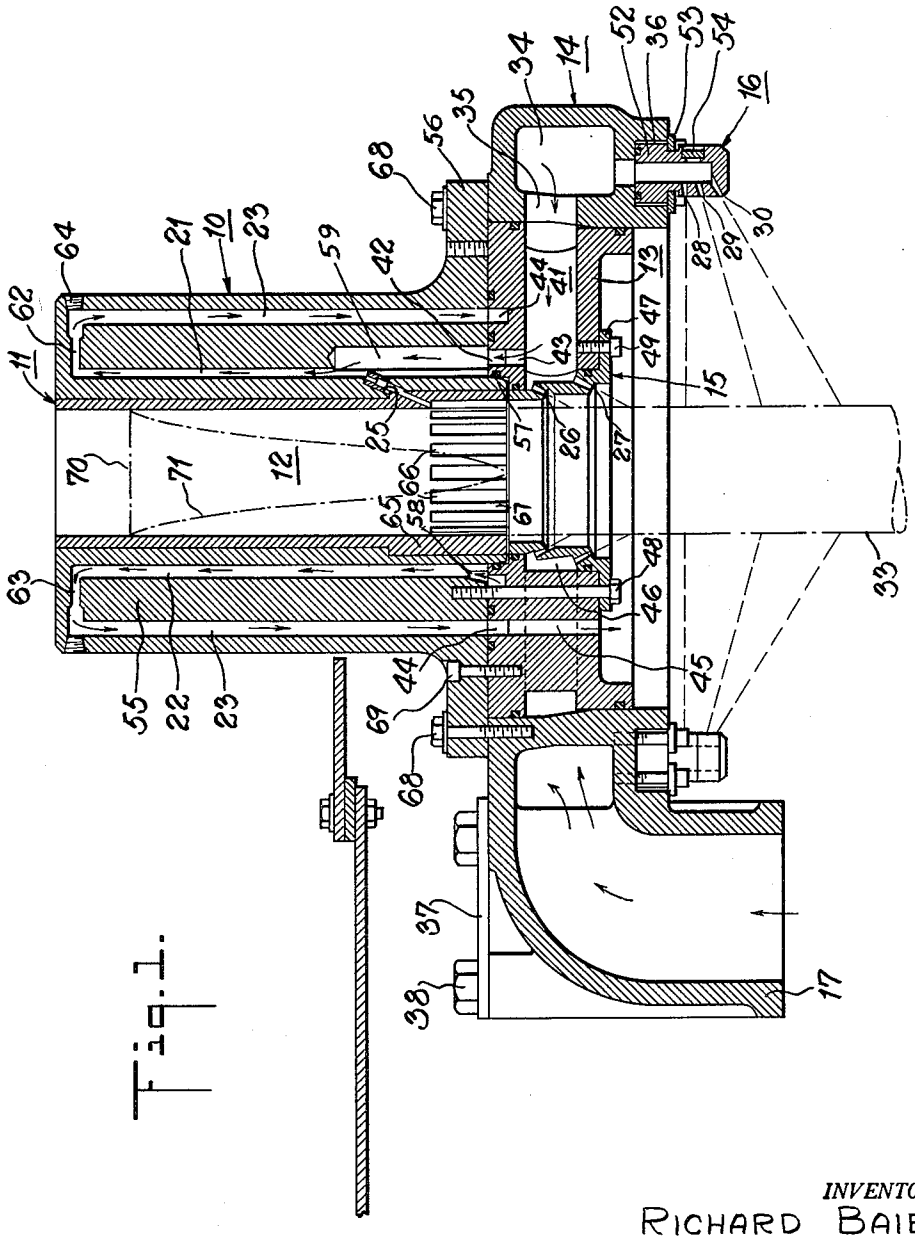


Fig. 1.

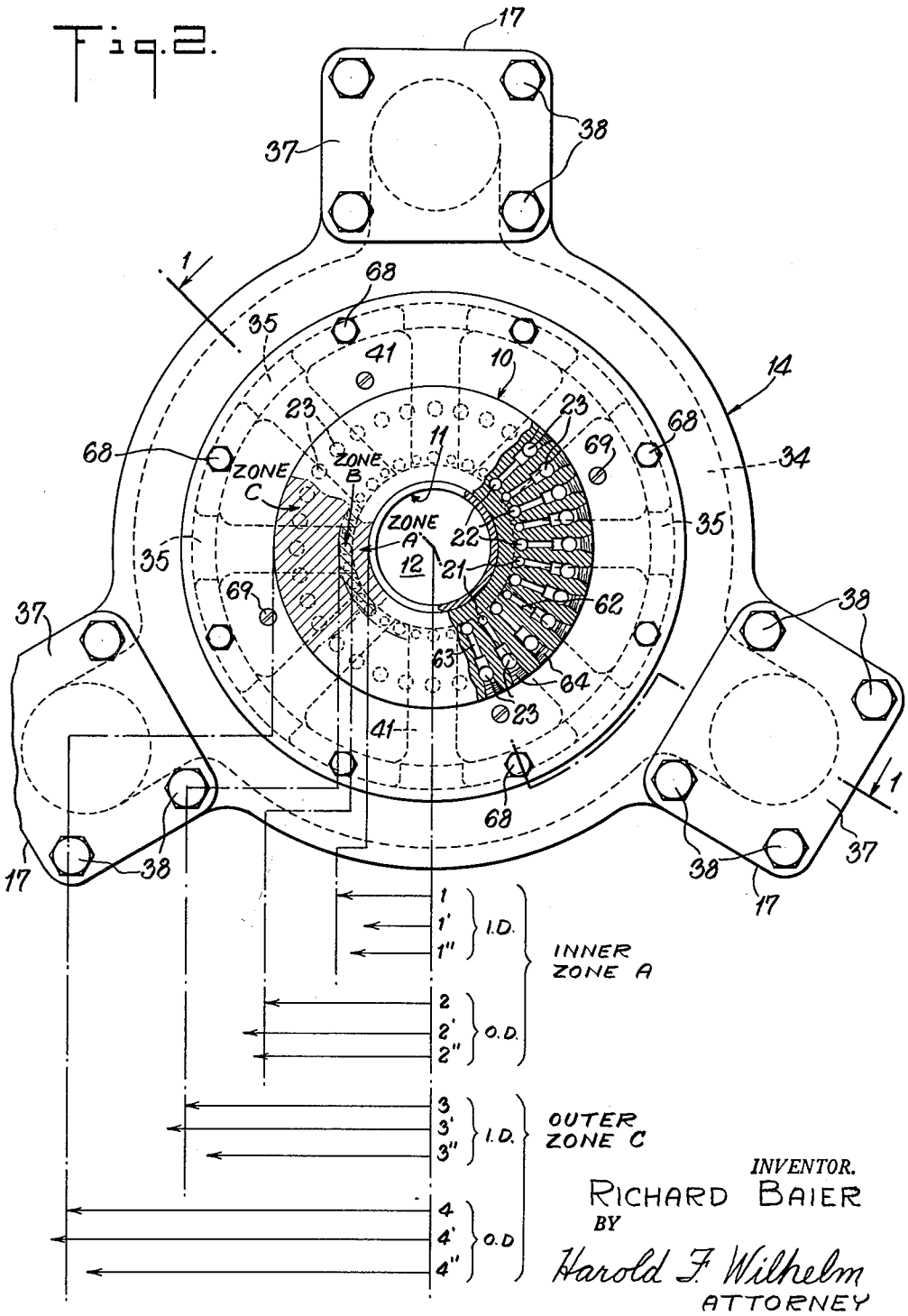
INVENTOR.
RICHARD BAIER
BY
Harold F. Wilhelm
ATTORNEY

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Fig. 2.



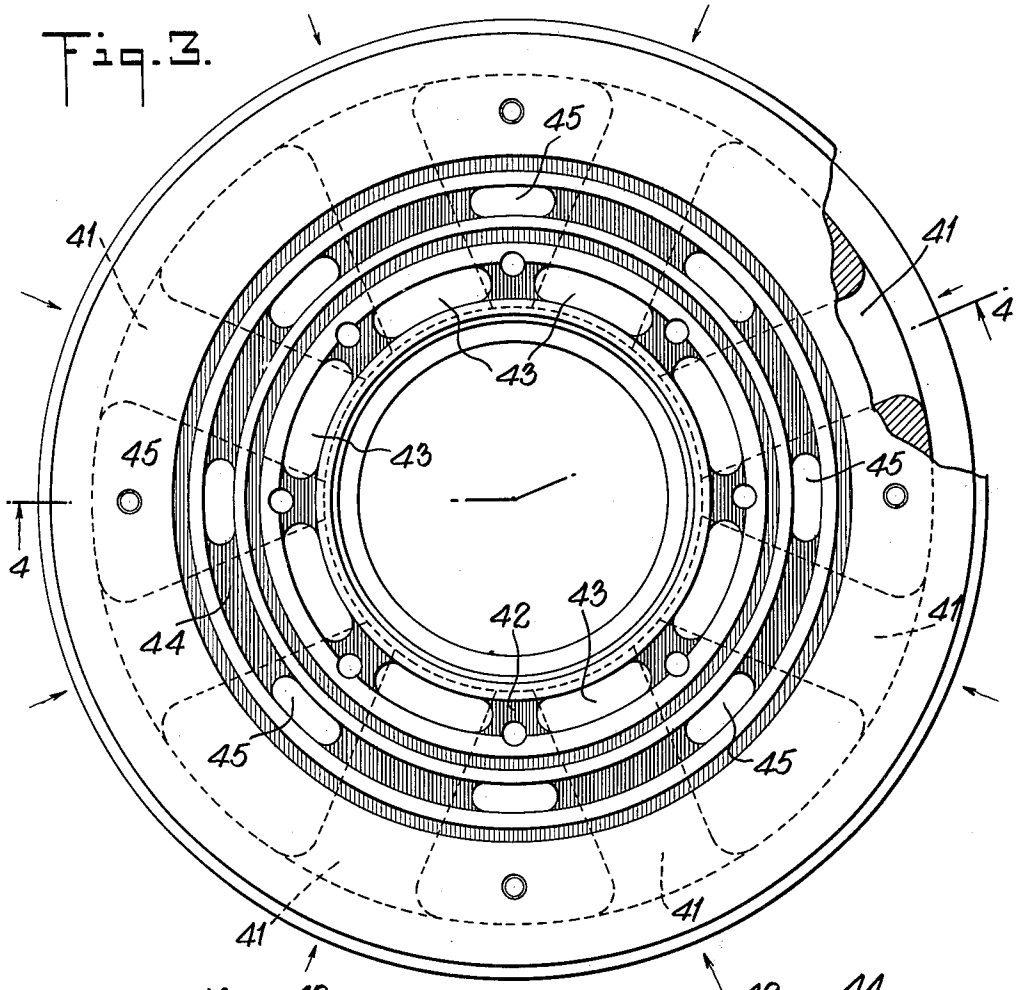
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Fig. 3.



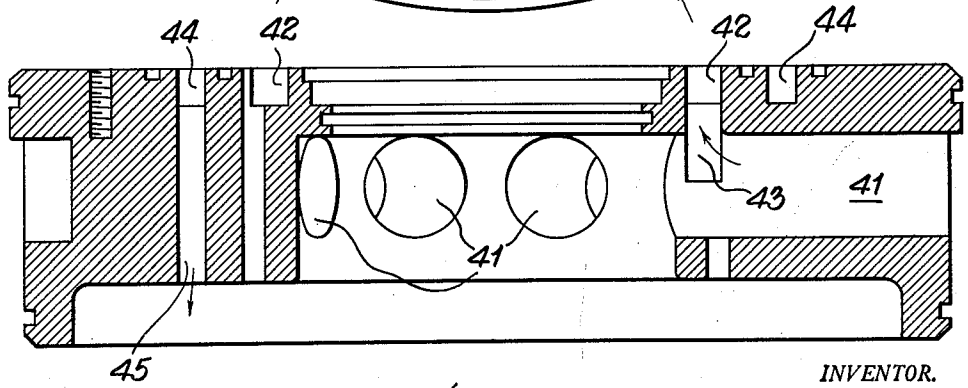


Fig. 4.

INVENTOR.
RICHARD BAIER
BY
Harold F. Wilhelm
ATTORNEY

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3,098,269

MOLD FOR CONTINUOUS CASTING

Richard Baier, New Brunswick, N.J., assignor to American Smelting and Refining Company, New York, N.Y., a corporation of New Jersey

Filed May 9, 1960, Ser. No. 27,930
4 Claims. (Cl. 22—57.2)

The invention relates to molds for continuous casting, and more particularly to the type of mold sometimes referred to as the open top or furnace-disconnected type.

When prior metal molds, either with or without a graphite liner, are run at high temperatures in a continuous casting operation, they quickly warp out of shape and take a permanent set requiring frequent repairs. For example, when casting phosphorized copper billets in a mold of annealed copper having a graphite liner, the circular pocket may become oval at axially spaced points in the mold, with the major axes of the two ovals at right angles to each other.

With higher casting speeds, the mold must dissipate increasingly larger amounts of heat. To increase heat dissipation, the mold pockets are tapered and the embryo casting is forcibly pulled through the mold, thus forcing the taper on the casting against the taper on the mold, increasing contact pressure and plastically deforming the product. This type of operation, sometimes referred to as the use of a "forced taper," is disclosed and claimed in my application Serial No. 724,114, filed March 26, 1958.

When continuously casting certain metals, such as copper base metals, in a metal mold, it is desirable to use a graphite liner. To obtain good heat transfer, these liners are given a compression fit with the metal jacket. Such compression fit is disclosed in Wieland Patent No. 2,871,530, granted February 3, 1959.

With mold tapers or a graphite liner, the lack of stability presents increased difficulties, particularly when casting at high speeds. In the case of graphite liners, the warping impairs the compression fit between liner and metal jacket, seriously reducing heat dissipation; with the forced taper, the warping causes non-uniform contact between casting and mold, and even loss of contact, also seriously reducing heat dissipation. When both liner and forced taper are used in the same operation, these difficulties are compounded.

The invention proposes to overcome mold instability and thus overcome the above difficulties, in a simple and reliable manner.

According to one preferred form of the invention, the mold comprises a forged block of copper having a mold cavity with open top and open bottom. A graphite liner is compression-fitted inside the mold cavity. The metal wall surrounding the mold cavity is made comparatively thick. To assist in understanding the invention, the thick metal wall may be considered as composed of three annular cylindrical zones, all rigidly connected together. The inner zone adjacent the graphite liner is comparatively thin, the intermediate zone contains a series of axially extending cooling passages, and the outer zone is comparatively thick. These cooling passages may constitute the supply or up-passages and may extend upwardly from the bottom of the block to the top where they are connected to discharge down-passages located in the outer thick zone. By keeping the outer zone at room temperature and giving it sufficient structural strength, the warping or expansive movement of the inner zone, which is subject to the high casting temperature, can be closely controlled.

For supplying the block with cooling water, an inner manifold is disposed under the block, surrounded by an

annular header. Water is supplied to the annular header whence it passes inwardly, through radial passages in the manifold, to an annular groove in the upper surface of the manifold which connects with the series of up-passages in the block. The manifold has a second groove in its upper surface connecting with the down-passages of the block and connecting also with elongate openings passing through the manifold and disposed between the radial manifold passages, for conveying used water to the collecting basin.

Certain of the block up-passages are enlarged and provided with nozzles which direct water at high velocity against the embryo casting while it is still being supported by the mold. A spray ring is positioned inside the annular manifold, which spray ring has a series of nozzle openings. The spray ring closes off the manifold radial passages.

To further cool the emerging casting, a series of spray posts may be provided. The outer header has a bottom groove in which the spray posts are disposed and secured. Each spray post may have a series of nozzles which direct high velocity water against the emerging casting.

All of the water discharged by the down-passages and by the nozzles is caught in a catch basin whence it is cooled and recirculated. Suitable pumps are provided for applying the cooled water to the header under high pressure so as to apply high pressure to the several nozzles. The water is circulated in huge volumes so that, in spite of the great quantities of heat it absorbs, the temperature of the exit water may be as littel as 10° F. higher than the entrance water, which ordinarily is at outside air temperature.

Other objects and features of the invention will be more apparent from the following description when considered with the following drawings, in which:

FIG. 1 is a vertical section through a mold according to the invention;

FIG. 2 is a top plan view of the mold;

FIG. 3 is a top plan view of the mold manifold; and

FIG. 4 is a vertical section on the line 4—4 of FIG. 3.

In the following description and in the claims, various details are identified by specific names, for convenience, but they are intended to be as generic in their application as the art will permit.

Like reference characters denote like parts in the several figures of the drawings.

In the accompanying drawings and description forming part of this specification, certain specific disclosure of the invention is made for purposes of explanation, but it will be understood that the details may be modified in various respects without departure from the broad aspect of the invention.

Referring now to the drawings, a brief description of the mold will first be given, after which the mold will be described more in detail.

The mold comprises, in general, a block of metal **10**, a graphite liner **11** having a circular cavity or pocket **12**. The block connects with a manifold ring of metal **13**. Surrounding ring **13** is metal mold header **14**. Closing off the central openings of the manifold **13** is a metal spray ring **15**. A series of metal spray posts **16** depend from the bottom of the header **14**.

The water flow will be briefly traced. Water is supplied at high pressure from pumps, not shown, to feed legs **17** of header **14**. The water then passes inwardly through radial ducts **41** of manifold **13** to top groove **42**, thence to up-bores **21** and **22** of block **10**, thence through down-bores **23** to elongate holes **45** in manifold **13** to a catch basin (not shown) under the mold. Water is supplied to six levels of high velocity nozzles **25**, **26**, **27**, **28**, **29** and **30**. The streams from these nozzles are indicated by lines

extending to the cast product 33, which lines have the same reference numbers as the nozzles, for convenience.

It will be understood that the mold assembly is mounted on a suitable vertically reciprocating platform, not shown, so that the mold may be vertically reciprocated in accordance with conventional practice. One form of mounting for the mold is disclosed in my copending application Serial No. 847,748, filed October 21, 1959.

The mold will now be described more in detail.

The mold header 14 is a metal casting and has three inlet legs 17 which feed an annular duct 34. Duct 34 feeds eight radial openings 35 which register with feed-in ducts 41 in manifold 13. Header 14 is provided with an annular bottom recess 36 in which are located the several spray posts 16, as described hereinafter. Plate washers 37 and bolts 38 hold down the header 14 on the platform, not shown.

Manifold 13 has eight radial in-feed ducts 41 which feed elongate holes 43 which, in turn supply top feed groove 42. Surrounding groove 42 is top exhaust groove 44 which connects with elongate exhaust holes 45 from which the water falls to the catch basin.

The spray ring 15 forms with the manifold 13 an annular duct 46. The ring 15 is stepped, and has a series of upper nozzle orifices 26 and a set of lower nozzle orifices 27. The ring 15 has a base flange 47. Long bolts 48 pass through the base flange and through the manifold 13 up into the block; short bolts 49 pass through the base flange and are threaded into the manifold 13.

Each spray post 16 comprises a base 52 located in recess 36. The post 16 has a bore and three nozzle orifices 28, 29 and 30. A series of washers and bolts 53 clamp the nozzle posts up against the header 14 in any suitable manner.

Each spray post 16 has a back closure plate 54. These plates give access to the central bore of the post and permit drilling of the several orifices 28, 29 and 30, which, it will be noted, are tapered, converging downstream with respect to water flow. After the orifices are drilled, the back plate 54 is fixed in permanent relationship to the plug as by welding.

The block 10 comprises a heavy cylindrical body 55 having a circular cylindrical cavity or pocket having an enlarged lower end and receiving the liner 11. Block 10 has a radial base flange 56 and a depending cylindrical flange 57. The block has an annular bottom groove 58 feeding a series of inner up-bores 21 and 22. Bottom groove 58 registers with top feed groove 42 of the manifold 13 and is fed thereby.

The up-bores 21 communicate with a series of vertical nozzle bores 59. These bores have nozzle openings in which are screwed stainless steel nozzle bushings 25. These bushings deliver high speed streams of water at an angle of less than 30°, preferably about 23°, with respect to the central axis of the mold, which in the preferred form is vertical. The up-bores 22 are disposed intermediate the up-bores 21.

Down-bores 23 are provided to discharge water from the block. There is one down-bore for each of the up-bores 21 and 22. The down-bores all register with the top groove 44 in the manifold, whence the water discharges through elongate holes 45 to the catch basin.

Connecting the up-bores 21, 22 and down-bores 23 are cross bores 62 and 63 at the top of the mold. These cross bores are somewhat restricted in diameter so as to insure placing adequate pressure on the several nozzles 25 and thus to deliver high speed water jets. Top plugs 64 close the openings which are necessary for the boring of the top bores 62 and 63.

The graphite liner 11 has an enlarged lower end 65 to fit the enlarged cavity in the block 10. The liner has circular, cylindrical outside surfaces to fit the block. The liner 11 has a circular, substantially cylindrical inner surface forming the mold pocket or cavity 12. The pocket 12 may converge slightly downstream to provide mold tapers as described more in detail below.

The graphite liner 11 is fitted into the block 10 by a compression fit discussed more in detail below. This may take the form of a press fit or a shrink fit. As an example of a press fit, the liner is made oversize and forced into the block while both members are cold. As an example of a shrink fit, the block 10 may be heated and the oversize liner slipped in while the block is hot. In any event, the compression fit must be sufficiently severe to maintain, under casting conditions, a fluid-free, solid-to-solid contact at the interface between block and liner.

The thicker wall 65 of the liner 11 is provided with a series of vertical recesses 66, forming ribs 67. The liner also has nozzle openings connecting the several recesses 66 and the nozzle bushings 25, so that the high speed jets of water are delivered to the embryo casting 33 while the casting is being supported by the ribs 67.

In operation, molten metal, for example, phosphorized copper, is fed into the open top of the mold pocket, and the cast round billet 33 is withdrawn from the bottom. The speed of metal feed and withdrawal is such as to maintain a free molten metal surface 70 near the top of the mold. The speed of casting and rate of cooling is such that the congealing metal forms a crater shell 71 having a deep crater.

The casting 33 is cooled in three axially spaced zones: in the top zone cooling is by the direct contact with the solid graphite wall; in the intermediate zone cooling is by both the ribs 67 and by the streams of water from jets 25; and in the lowermost zone cooling is by water only, from jets 26 to 30.

The mold pocket wall 12 is especially tapered. It is provided with what may be called, for convenience, a forced taper, to distinguish it from tapers which may be called natural tapers. With the forced taper the steepness of taper is so related to linear casting speed that the shrinkage taper on the cast product is forcibly wedged against the taper on the mold pocket so as to plastically deform the red hot tube comprising the crater shell enclosing the liquid core.

The forced taper operation, in a sense, is similar to wire drawing. It requires the establishment of a crater shell with a long and deep V, with a strong but plastic shell wall surrounding a soft liquid center, a combination that is readily deformed by pulling it through the tapered mold.

The natural taper may be defined as that taper which corresponds to the shrinkage pattern of the congealing casting at any particular casting speed, that is to say, the casting will move through the mold without any external force applied. A forced taper is steeper (that is, at a larger angle to vertical) than a natural taper for the same linear casting speed, and requires a positive pull on the cast product to pull it from the mold. It should be noted that a taper, which is a natural taper for any given casting speed and rate of heat extraction, becomes a forced taper if that casting speed is increased.

Attention is called to my copending application Serial No. 724,114, above referred to, for further explanation of the forced taper and for an example of a process of casting which can use the present invention to advantage. The present invention is now used to practice said process commercially.

The materials of the mold may be varied, depending upon the metals being cast and operating conditions. For example, for casting copper base metals, such as tough pitch copper or phosphorized coppers, it is desirable that the block 10 be a copper forging. A forging has a better crystalline structure than a casting. The manifold 13, spray ring 15, header 14 and spray posts 16 may be of high tin bronze, as these have the ability to withstand water erosion. The top level nozzles 25 may be of stainless steel. The liner may be of graphite or graphitic

carbons. The passages in header **14** are cast in, all other water passages are machined.

The several parts of the mold are suitably bolted together and sealed against water leakage. In general, sealing is accomplished by O-rings seated in suitable grooves. The outer header **14** is secured to the block **10** by bolts **68**. The inner manifold **13** is secured to the block **10** by bolts **48** and **69**. The spray ring **15** is secured to manimold **13** by bolts **48** and **49**. There are three O-rings between block **10** and manifold **13**; there are two O-rings between spray ring **15** and manifold **13**; there are two O-rings between header **14** and manifold **13**, and there is a single O-ring between each post **16** and header **14**.

It will be understood that after the graphite liner is replaced several times, the inside diameter of the block must be re-machined and a thicker liner used to maintain a mold cavity **12** of the same nominal diameter. The block **10** is so constructed to allow for necessary re-machining.

The up-bores **21**, **22** must be properly spaced. They must be close enough to form a thermal barrier to heat flow from the hot metal in the mold pocket; no heat must reach outer zone C which should preferably remain at room temperature. On the other hand, the up-bores **21**, **22** must be sufficiently spaced to provide strong ribs between zones A and C. The bores must be of such diameter as to provide high velocity flow of cooling water to avoid skin effect or film effect.

To assist in understanding the forces exerted by the various parts of the mold on each other during temperature cycles from room temperature to temperatures under casting conditions back to room temperature, the block may be considered as divided into three annular sleeve-like zones A, B and C. Zone A is the inner zone which is in contact with the graphite liner on one side, and the up-bore cooling passages **21**, **22** on the other side. Zone B comprises the up-bores **21**, **22**. Zone C comprises the thick wall outside of zone B, including the down-bores **23**. Thus, zone B comprises integral ribs between the several up-bores, integrally connecting zone A and zone C. If desired, the down-bores **23** may be shortened and water exhausted from the sides of the block **10**.

The graphite liner is tightly fitted inside zone A, either by a shrink fit or a press fit, as described above. The interference, that is to say, the difference in diameter between the outside diameter of the liner and the inside diameter of zone A before assembly, in the commercial installation, is about 0.008 to 0.010 inch with a 3½ inch outside diameter liner. Tests show that by using the teachings of the invention, the interference can be reduced to approximately 0.003 to 0.004 inch or lower without seriously reducing heat transfer. The reasons will be apparent from the discussion given below.

When a new mold is placed in service, the inner zone A and the graphite liner become heated to elevated temperature. When casting phosphorized copper having a temperature of about 1980° F. in the mold, the graphite might assume an average temperature throughout its cross section of about 600° F., and the inner zone A, at the interface with the graphite liner, may assume a temperature of about 350° F. The inner zone A tries to expand but is restrained by outer zone C, which applies restraint through the integral ribs of zone B. Inner zone A thus goes into compression and outer zone C goes into tension. The condition now existing is the same as if inner zone A was an oversize sleeve (like the graphite liner that has been pressed into inner zone A).

The change in dimension due to expansions and contractions of the several zones under alternate heating and cooling are illustrated diagrammatically in FIG. 2. In this figure the inner diameters of inner zone A are indicated by **1**, **1′** or **1″**; its outer diameters by **2**, **2′** or **2″**. The inner diameters of outer zone C are indicated by **3**, **3′** or **3″** and its outer diameters by **4**, **4′** or **4″**.

The unprimed numerals indicate the diameters of a "new" mold before use; the single primes indicate the several diameters under the elevated temperature of continuous casing conditions; the double primes indicate the several diameters after the mold has cooled down to room temperature.

The length of the diameters in the diagram indicates direction of change in dimension, not amount of change. Thus, for example, considering the inner diameter of inner zone A, **1** indicates original length of this diameter; **1′** indicates that the diameter has decreased under heating; and **1″** indicates that the diameter at room temperature has increased relative to **1′** but does not come back to original length **1**.

The following is the condition of the several diameters when the mold is at operating temperature. The inner diameter of inner zone A actually becomes smaller than its free diameter (compare **1** with **1′**); and the outer diameter of inner zone A becomes larger (compare **2** with **2′**). The inner diameter of outer zone C becomes larger (compare **3** with **3′**) and the outer diameter of outer zone C becomes larger (compare **4** with **4′**). This is because the elastic or plastic volume expansion of inner zone A elastically stretches outer zone C.

The stress on each zone may be said to be an inverse function of the mass in the particular zone; see, for example, the wedge-shaped area cross-hatched in FIG. 2. In the design which has proven satisfactory in commercial operation, the ratio is about 6 to 1. That is to say, the cross-section of zone C is six times the cross-section of zone A. The outer zone C restricts the outward expansion of inner zone A to about one-sixth of its free, unrestrained expansion.

It will thus be seen that this restraint forces the metal in inner zone A to move inwardly, thereby actually reducing the bore of the block, and further applying additional load to the outside of the graphite liner. For this reason the graphite liner can be more loosely fitted, as an original fit, than in certain prior molds, and still maintain proper contact.

It will be understood that the metal in inner zone A is stressed beyond its yield point and takes a permanent set. The volume of outer zone C is such that stress applied thereto by volume change of zone A will not strain zone C beyond its yield point. Outer zone C must be thick enough that its outside diameter is not permanently substantially increased after use.

It is important that inner zone A be integral with outer zone C. Upon cooling, inner zone A tends to shrink; its inner diameter increases (compare **1′** with **1″**) and its outer diameter decreases (compare **2′** and **2″**); this exerts an inward pull on outer zone C; the inner diameter of zone C decreaes (compare **3′** with **3″**) and its outer diameter decreases (compare **4′** with **4″**). This puts outer zone C in compression and inner zone A in tension.

Upon heating up the mold in a subsequent operation, the several diameters change from the double prime positions to the single prime positions in FIG. 2; they never acquire the unprimed position under alternate heating and cooling.

The above discussion of effect of expansion and contraction between the several zones and between block and liner refers primarily to radial and circumferential directions. It will be understood that these effects apply also to the axial direction, except that axial forces acting between block and liner cause the liner to slide axially with respect to the block.

It is apparent that by choice of a proper ratio of volume of inner zone A to outer zone C, the inside diameter of zone A can be held to little or no increase in dimension; and can actually be made to decrease in dimension, when raised from room to operating temperature. Thus, no loss of contact between graphite liner and metal block can occur.

It will be understood that tremendous quantities of

water are circulated and applied at high pressure. For example, in one commercial installation for continuously casting a 3-inch diameter phosphorized copper billet at the rate of about 55 inches per minute, about 700 gallons of water per minute at about 180 pounds per square inch pressure was applied to the legs of the header. This water puts high pressure on the several nozzles; these deliver streams of water at high speed and in such amounts as to cool the emerging casting without creating any steam. This water continues to circulate through the up-bores and through the down-bores back into the catch basin. The amount of circulation may be such that the water temperature of the water falling into the catch basin is only 10° F. above the temperature of the water supplied to the legs of the header.

The teachings of the invention may be applied to molds of various cross-sections for casting products of various cross-sections; but they are particularly applicable to circular cross-sections and to those non-circular cross-sections which do not depart too much from circular, that is, which have cross-sections more or less symmetrical around a longitudinal axis with respect to radial heat transfer; as, for example, equilateral triangle, square, hexagon, octagon, and even an oblong which does not depart too much from a square.

The graphite liner may be of any grade or quality of graphite, including materials containing graphite, such as graphite-coated carbons; the term graphite as used in the claims is intended to cover such equivalents. In general, it is preferred to use the type of graphite which has maximum density and mechanical strength, as well as maximum heat conductivity.

While certain novel features of the invention have been disclosed herein, and are pointed out in the annexed claims, it will be understood that various omissions, substitutions and changes may be made by those skilled in the art without departing from the spirit of the invention.

What is claimed is:

1. A mold for continuously casting metal, of the type comprising a metal wall enclosing a mold cavity, a graphite liner fitted in said mold cavity, said metal wall comprising in effect, three sleeve-like zones, namely, an inner zone, an intermediate zone and an outer zone, the metal of said intermediate zone being integral with the adjoining metal of said inner and outer zone, said intermediate zone having a plurality of cooling passages separated by connecting members integrally connecting said inner and outer zones, said cooling passages being close enough together to form a heat barrier between inner and outer zones, said connecting members being close enough together and sufficiently heavy to provide a stiff connection between inner and outer zones, said inner zone, under the temperature of operation, being subject to expansion and plastic deformation, said outer zone being of such strength that, at its lower temperature maintained by the heat barrier of said intermediate zone, it is not plastically deformed by the forces exerted upon it by said inner zone and therefore enables said connecting members to restrict plastic deformation and outward expansion of said inner zone and thus to hold said liner under sufficient compression to maintain a fluid-free, solid-to-solid contact at the interface between metal wall and liner.

2. A mold according to claim 1, said wall, graphite liner and cavity being substantially symmetrical about the longitudinal axis of the mold.

3. A mold according to claim 1, the cavity of said graphite liner converging toward its discharge end to provide mold tapers.

4. A mold according to claim 1, the cooling passages in said intermediate zone comprising a series of cooling bores surroundng the mold cavity, said bores extending generally parallel to the axis of the cavity, and additional passages connecting certain of said bores and the cavity of said liner to apply cooling fluid directly to the embryo casting.

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