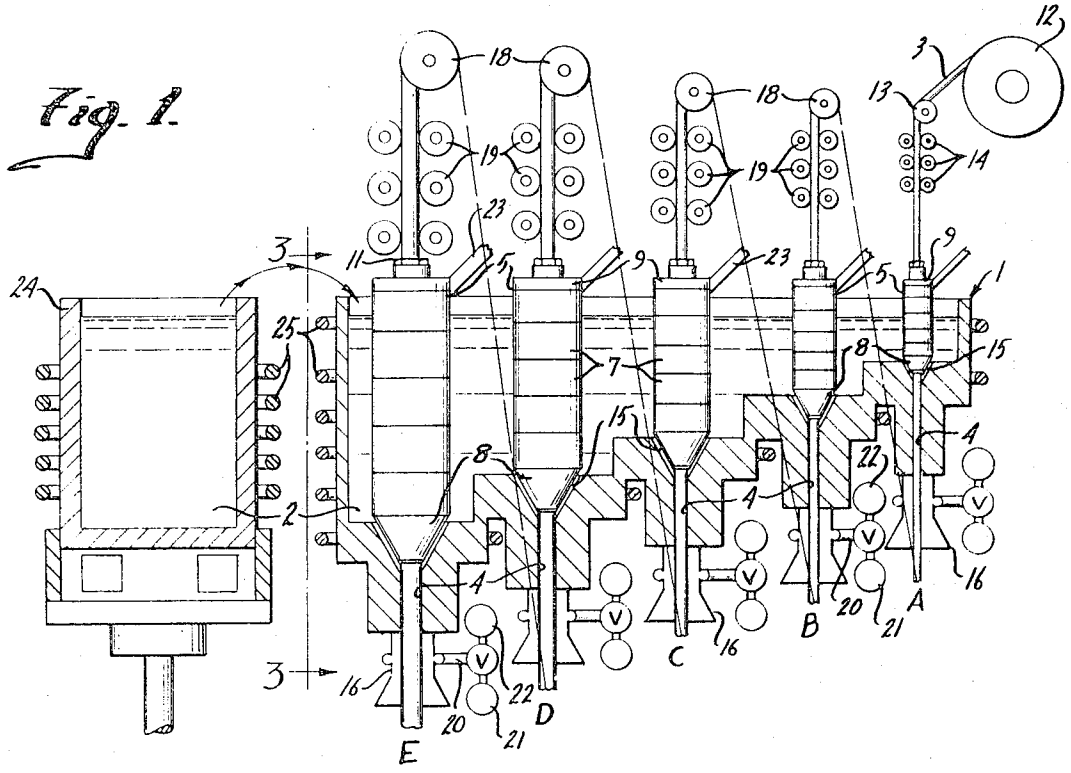
May 30, 1972 S. V. WILLIAMS 3,666,537

METHOD OF CONTINUOUSLY TEEMING AND SOLIDIFYING VIRGIN FLUID METALS

Filed May 1, 1969 2 Sheets-Sheet 1

Fig. 1.



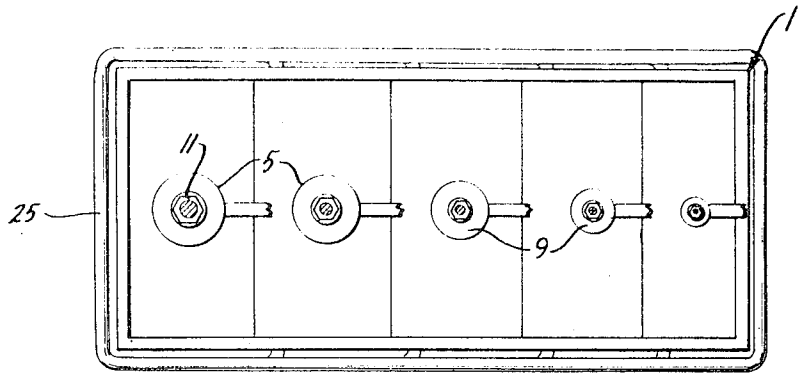


Fig. 2.

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METHOD OF CONTINUOUSLY TEEMING AND SOLIDIFYING VIRGIN FLUID METALS

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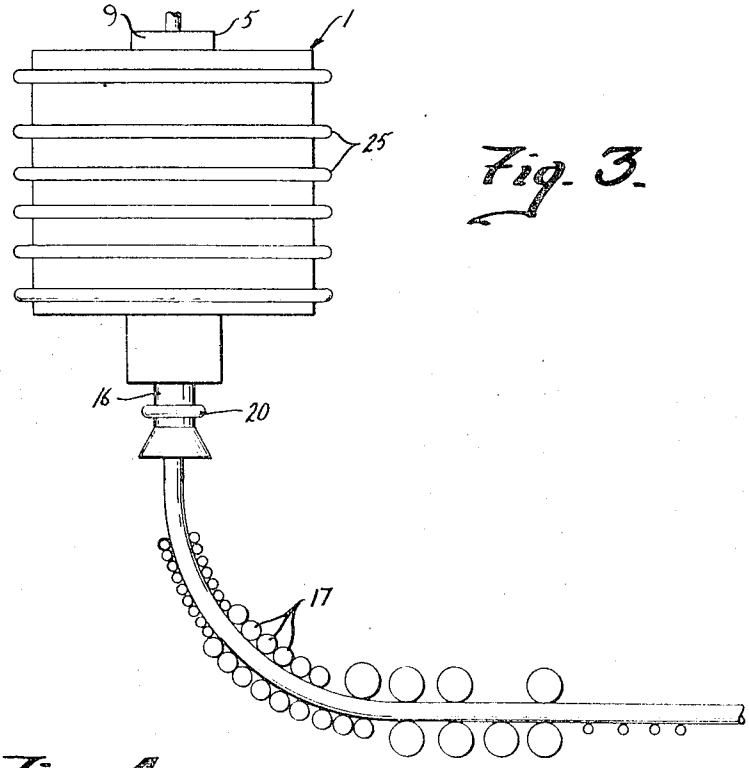
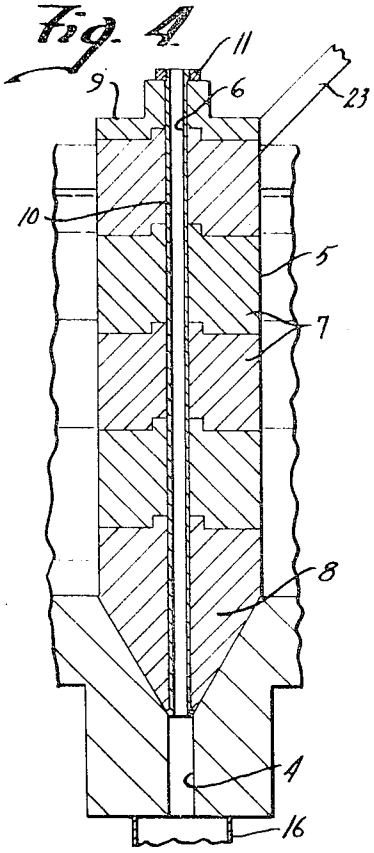


Fig. 3.

Fig. 4.



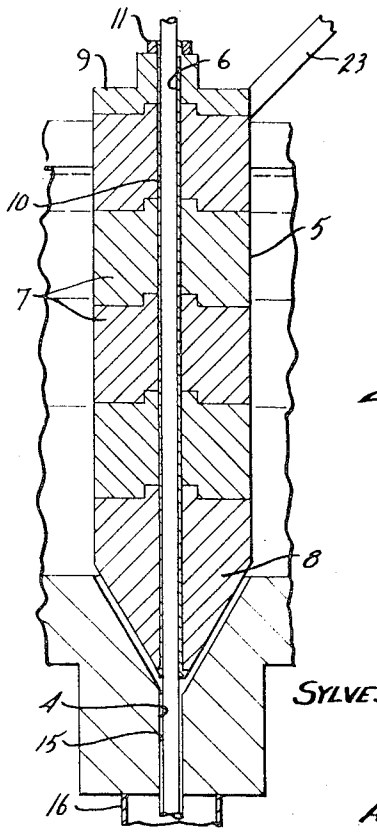


Fig. 5.

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3,666,537

METHOD OF CONTINUOUSLY TEEMING AND SOLIDIFYING VIRGIN FLUID METALS

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Continuation-in-part of application Ser. No. 497,177, Oct. 18, 1965. This application May 1, 1969, Ser. No. 820,847

Int. Cl. C23c *1/00*

U.S. Cl. 117—114 R 4 Claims

ABSTRACT OF THE DISCLOSURE

Virgin fluid metal is continuously teemed and solidified from the inside outwardly by accretion upon a continuously moving solid body of the same metal.

CROSS REFERENCES

This application is a continuation-in-part of application Ser. No. 497,177 filed Oct. 18, 1965 and now abandoned.

This invention relates to a method of continuously teeming and solidifying virgin fluid metals.

The invention is believed to be particularly applicable in the production of steel and various ferrous metal alloys refined by pyrometallurgical and electrometallurgical processes.

The metals being refined in such processes are generally made more fluid by the combination of oxygen and the inclusion therein of gaseous state constituents and impurities which need to be removed by the teeming process.

Commercially acceptable teeming processes heretofore employed have involved the use of ingot molds wherein the fluid metal first solidified at the outer walls of the mold with the teeming action progressing from the outer surface toward the middle, and which produced the inevitable undesirable shrink cavities or pipes and segregation of impurities centrally of the ingot. The same problems arise in the more recent practices of continuously pouring the fluid metal into a series of connected smaller oscillating molds generally with water-cooled copper side walls. The starting stool has a water-cooled copper surface which lowers from the walls when sufficient skin thickness of solidified metal is formed to contain the fluid metal therein.

In all instances, where solidification commences from the outside of a body of fluid virgin metal, the gases and impurities become entrapped and remain in the solidified ingot either in the form of shrink cavities or pipes with segregated and dissolved gases and impurities.

The present invention is directed to a new and revolutionary process for teeming and solidifying virgin fluid metals wherein the fluid metal is teemed and solidified by bringing a solid state core of the same metal into the center of a moving column of fluid metal, thereby commencing solidification at the interface between the solid state and meeting fluid state, and promote an outward teeming of the gases and impurities and substantially instantaneous solidification of the metal at the interface and progressively growing outward in accretions as the interface between the solid state and the fluid state moves outwardly.

The present invention is based upon the concept of flowing of the fluid metal downwardly around a downwardly moving rod of the same metal which fosters accretion by fusion of the two at their meeting surfaces resulting in core crystallization growth as the metal solidifies from the inside out with the outer surface remaining in a fluid state so that the hot gases and impurities are free to escape laterally and to be expelled from the metal as the latter crystallizes and solidifies, without any interference from a surrounding liquid or solid state environment.

In this process, the freedom for escape of the gaseous impurities which generally consist of the higher energy atoms, makes it possible for the remaining atoms to spontaneously reduce their energy and take their permanent position in the crystal lattice work of the solid state body without danger of returning to a liquid state. Thus, the solidification or change of state of the atoms becomes spontaneous and permanent.

In carrying out the process, the core rod is moved downwardly through a tubular shield and stopper in the fluid bath of virgin metal and the fluid metal is allowed to escape at a controlled rate in a continuous tubular stream or moving column about the core rod and which coagulates and coalesces the inner surface of the fluid metal, and the two move downwardly together.

The coagulation of the inner surface of the fluid stream with the outer surface of the core rod as they move downwardly together triggers the spontaneous change of the accretion metal from a fluid state to a liquid state and then to the solid state. Theoretically, one pound of solid state metal can solidify about five pounds of fluid state metal. The volume relationship between the fluid and solid states involved should therefore be well kept within that ratio.

The core rod is kept out of contact with the fluid metal in the tundish and does no appreciably begin to lose its solidifying capacity until it comes in contact with the downward flow of virgin metal which has passed through the discharge nozzle from the tundish.

The apparatus for carrying out the process may be quite simple and merely comprises a crucible and a tundish for the fluid metal having a pouring nozzle in its bottom with a stopper. The stopper is made tubular and extends to a point above the fluid metal so that the core rod is fed down through the hollow stopper without contacting the fluid metal until the rod emerges from the stopper at the discharge nozzle for the fluid metal. The fluid metal is applied to the rod by adjustably lifting the stopper and allowing a predetermined and controlled flow of fluid downwardly embracing the rod. Dropping of the stopper to its seat stops the flow of fluid metal.

In general, the relative volume and temperature or energy level of the fluid and solid state bodies and the rate of travel will determine the length of the solidification zone required beneath the tundish and before the accretion on the solid state core can be bent laterally for horizontal movement.

The rod is preferably moved downwardly at a rate exceeding the downward gravity discharge rate for the fluid metal from the nozzle. In practice, the speed of the rod through the nozzle may be of the order of 340 feet per minute. The speed may be higher for metals that are more fluid and may be lower for metals that are less fluid.

It is contemplated that the solidified structure may be returned to another stopper for a successive accretion or fusion operation thereon, and that as many successive accretions may be made as is practical for any given operation. In this way, a core rod of one-half inch diameter initially, may be built up to a final solidified billet having a diameter of the required inches.

As an example of possible accretion in successive passes of the core through the tundish, the following is possible:

	Starting size	Accretion thickness	Resulting size
Pass:			
1	½"	¼"	1"
2	1"	5/16"	1⅝"
3	1⅝"	5/16"	2¼"
4	2¼"	⅜"	3"
5	3"	⅜"	3¾"
6	3¾"	⅜"	4½"

Further passes may be made as desired.

The completed billets or shapes may be cut to suitable lengths and each will constitute in effect a billet of refined metal or alloy substantially free of defects. The costly blooming of ingots may be substantially eliminated. The continuous billet without being cut may be rolled directly into a desried rod, wire or other shape and coiled with or without further heating.

The metal in the tundish may be said to be in a fluid state composed of liquid phase metal and gaseous phase impurities generally in solution therein. The gaseous phase materials are generally of higher energy than the liquid phase metal, and the liquid metal is of substantially higher energy level than the solid state metal.

The final structure would be free of pipes, cavities, fissures, strikes, segregations and impurities, since the gaseous phase materials are forced to escape from the fluid state virgin metal as the liquid phase metal crystallizes or solidifies in coalesces with and crystallizes on the solid state core.

The present process is illustrated more or less schematically in the accompanying drawings in which:

FIG. 1 is a schematic illustration of the apparatus and process with the tundish for the fluid metal vertically sectioned generally on the longitudinal centerline thereof;

FIG. 2 is a top schematic plan view of the stoppers in place;

FIG. 3 is a schematic illustration taken generally transversely on line 3—3 of FIG. 1;

FIG. 4 is an enlarged detail transverse section showing a hollow stopper closed upon its seat; and

FIG. 5 is a view similar to FIG. 4 showing the stopper raised and the flow of metal during the teeming process.

Referring to the drawings, the crucible or tundish **1** is generally formed with a step bottom to provide for different and increasing depths of fluid metal **2** in the several fusion zones A, B, C, D and E. Any suitable number of fusion zones may be provided within the range of practical handling of the core rod **3** which increases in diameter by fusion and accretion at each zone.

Each fusion zone of crucible **1** has a nozzle opening **4** in the bottom for the discharge of fluid metal **2**, and which opening is closed by a stopper **5** at times other than during a teeming operation.

Each stopper **5** is tubular and has a central vertical opening **6** therethrough for the free passage or movement of rod **3** downwardly therethrough during a teeming operation.

Stoppers **5** are made up of a plurality of rings **7** of refractory ceramic material, each interlocked with its adjacent blocks, with a seat ring **8** at its lower end for seating in a nozzle opening **4**, a cap ring **9** at its upper end, and a tubular bolt **10** extending vertically through all of the blocks and secured at its lower end to seat ring **8** and having a threaded nut **11** at its upper end for tightening upon cap ring **9** and thereby completing the stopper.

Each stopper **5** should be of a length to extend substantially above the top of the fluid metal **2** in tundish **1** when the stopper is seated upon its nozzle opening **4**. For this purpose the number of rings **7** and the length of bolt **10** will be selected accordingly.

The shortest stopper **5** is in zone A, and each successive zone B, C, D and E has a longer stopper, determined by the amount of step in depth for the zone.

Also, the diameters of nozzle openings **4** and of stoppers **5** will be different in the different zones. The nozzle openings **4** and stopper **5** for zone A will have a diameter suited to the fusion accretion of metal upon the initial core rod **3** which may be in the order of less than one inch in diameter. The nozzle opening **4** and stopper **5** for the next zone B will have a diameter suited to the fusion accretion of metal upon the rod **3** after it has received a first layer of accretion metal and which may then be of a diameter somewhat in excess of one inch. The nozzle opening **4** and stopper **5** for each successive zone will have a diameter suited to the contiguous solidification of metal upon the rod **3** plus its accretion layers previously fused thereon in the process.

The mechanism for supplying and handling the rod **3** during the process is illustrated schematically in FIG. 1, and comprises, in general, a supply drum **12** from which the rod is fed over a sheave **13** and thereby aligned with the stopper **5** in zone A. As the rod **3** is fed downwardly toward stopper **5**, it passes through a set of straightening rolls **14** and then into the upper end of bolt **10** of the stopper.

As the rod **3** emerges from the bottom end of bolt **10** or stopper **5** and continues downwardly through the nozzle opening **4** in tundish **1**, fluid metal is released to flow with and embrace the rod by raising of the stopper, as indicated in FIG. 5.

The position of stopper **5** should be adjusted to give a desired maximum flow of fluid metal having regard to the speed of movement of rod **3** and to the practical thickness of accretion metal **15** that can be solidified upon the rod in a single pass.

As the rod **3** and its first layer of accretion metal **15** continues downwardly at a rapid rate, it passes through a chamber **16** where partial solidification takes place, and then down to a series of rollers **17** disposed to change its course gradually from a vertical to a horizontal path and then to a vertical return path leading to the second sheave **18** above zone B.

Sheave **18** feeds the work blank consisting of rod **3** and its first layer of accretion metal **15** downwardly through straightening rolls **19** and into the stopper **5** for zone B which in turn is adjustably raised to release fluid metal to the outer surface of metal **15** constituting the new outer surface of core material.

Each successive zone has a chamber **16** and rollers **17** for receiving the rod and its accretion layer of metal. Likewise, each successive zone has its sheave **18** and straightening rolls **19**. In each successive zone, the work blank will be larger in diameter, determined by the increment or layer of accretion metal added thereto at the next preceding zone.

The chamber **16** in each instance should be of such length as to effectively receive substantially all gaseous state impurities expelled from the accretion layer upon the rod prior to its reaching the rolls **17**.

Depending upon the characteristics of the metal or alloy being processed, the speed of movement of rod **3** and the amount of accretion flow being applied to the rod, it may be desirable to asperse inert gas into chamber **16** through connection **20** from source **21** to thereby flush out of chamber **16** the gases emitted from the fluid metal as it solidifies upon the downwardly moving rod **3**.

In general, at higher speeds and with larger amounts of accretion, it may be desirable to apply a partial vacuum to chamber **16** through connection **20** from vacuum source **22**, in which case the gases exuded from the accretion metal are more rapidly drawn off and the metal remains more fluid at its surface for a longer time. The partial vacuum has a tendency to draw cooling air into the lower end of chamber **16** and thereby effect cooling and solidification of the metal just prior to entering rolls **17**.

The movement of stopper **5** may be accomplished by any suitable mechanism, not shown, and which is connected to an arm **23** secured to the upper end of each stopper.

The tundish **1** may be maintained full of fluid metal to the desired level at all times by the auxiliary container, crucible or mixer **24** into which fluid metal is poured from ladles from time to time. The arrangement is such as to provide for possible return of the fluid metal from the tundish back to the crucible should the process become stopped for any reason and it becomes desirable to empty the tundish.

The fluid metal **2** in crucible **24** and/or in tundish **1** may be kept at a predetermined temperature by auxiliary electric induction heating means **25** extending around the crucible and tundish, and which may be designed to effect a stirring of the fluid metal.

The depth of fluid metal for each teeming zone is maintained to provide a pressure of fluid at the corresponding nozzle to give the necessary acceleration to the fluid flow through the nozzle whereby the accretion metal **15** flows onto rod **3** at nearly the downward speed of movement of the rod.

In the teeming process, the intimate contact between the tubular column of fluid flow and rod **3**, which may be assisted by maintaining a slight pressure in chamber **16** from connection **20** and which provides a very rapid energy transfer from the fluid column now on the solid rod **3**. As the fluid state metal comes into contact with the solid state core metal, there is an instantaneous equalization of the energy level of both surfaces with a coalescing of the atoms, which may be aptly referred to as "contiguous solidification." The resulting solidifying of the fluid metal from the core toward the outer surface is spontaneous at the meeting surfaces. This triggers the emission of the gases as solidification advances from the inner core surface outwardly toward the outer surface of the accretion.

As the fluid metal is solidified from the inside, gases entrapped therein are forced outwardly and escape into chamber **16** where they are flushed away by the moving gases flowing through the chamber, or are drawn away by the vacuum source, as previously described.

The virgin metal, being in a fluid state with entrapped gases present, becomes triggered rapidly toward solidification of the liquid state, and the freedom for escape of the gaseous state provides freedom in the environment for crystallization of the metal during solidification.

In this process, the size or volume relationship of fluid to solid state area is controlled by the orifice size of nozzles **4** effected by raising the stoppers **5**, the head of fluid metal at the zone from which the fluid metal flows, and the speed of travel of the solid state core.

Core crystallization growth or contiguous solidification is obtained entirely without molds with their fixed dimensions and shapes to confine and compress the fluid state while the change in state takes place. There is no restricting volume of fluid metal present during the solidification. The solid state is therefore free to form spontaneously and to maintain its stable properties and shape. Thus, the core growth or contiguous solidification is always from the inside out toward the periphery.

The high energy atoms of the entrapped gaseous state present in the fluid state of the virgin metal are encouraged by the environment to escape outwardly to the surrounding gaseous environment so that the liquid atoms of the virgin metal can drop abruptly to the energy level of the solid state freely with substantially no slowing down or arresting of the change.

This change in energy level of the atoms takes place continuously in predetermined regions of travel of the rod **3** and accretion metal **15** in chamber **16** or beneath it. The liquid state atoms seek the lower energy of the solid state and take their place and maintain it in the natural lattice work inherent in metals of the solid state,

without interference from the higher energy atoms of the gaseous state.

The nucleus of the latent solid state atoms is not encouraged to return to an excited condition of liquid state by the presence of higher energy gaseous state atoms or molecules as occurs in ingot casting processes.

The orbiting electrons of the nucleus can drop down closer to their fixed orbits of the solid state, and the free electrons can join the nucleus, thus offering them the lowest energy level to be found in the solid state. The bonding action of the free electrons becomes instantaneous, thereby establishing the solid state and shape of the metal crystals.

The rate of travel of the moving solid state core through the hollow stopper can be varied independently and needs only to be adjusted to effect solidification of the optimum thickness of the newly grown solid state desired on its periphery. The core maintains its metallic bonding free electrons and brings under control the corresponding free bonding electrons of the moving liquid state embracing its periphery. As the higher energy electrons of the gaseous state leave to the outside, the lower energy electrons of the liquid state remain for solidification on the growing surface of the parent core.

The solid state grows exponentially as the liquid state decreases or shrinks exponentially.

An adjustment between the relative rate of travel of the core **3** and the surrounding column of fluid state virgin metal can effect relative elongation or shortening of the fluid state column and determine or establish the desired depth of solid state growth in any given fusion or teeming operation. Thus, a faster core speed for a given nozzle opening reduces the thickness of solid state accretion metal **15**, and a slower core speed for the same nozzle opening will increase the thickness of solid state accretion metal **15**.

The greater the surface area and moving mass of the solid state, the larger the volume of fluid metal that can be solidified in any one cycle.

In carrying out the invention either a single layer of accretion metal **15** may be fused upon the core rod **3**, or by recycling as illustrated in FIGS. 1 to 3, a multiple number of layers of accretion metal may be successively fused upon the rod. The final size of the rod or end product will be limited depending upon practical handling facilities and characteristics of the metal or alloy being teemed.

Where recycling is employed, each successive layer of deposited metal fused upon its predecessor will effect a re-crystallization and refinement of the metal of the previous layer, thereby improving the physical properties of the final structure. The process utilizes the forces of gravity to accelerate the fluid flow of virgin metal to generally simulate the speed of rod movement. In the present process, the core rod never comes into contact with the fluid meatl in the container or tundish **1** and thus does not melt prior to the fusion or solidification with the accreted metal.

The general fit of the lower end of the stopper **5** with the moving core rod **3** taken with the speed of the moving core rod provides in effect a seal that prevents fluid metal from rising inside the hollow stopper, and thus the core rod does not come into contact with the fluid metal until it reaches the nozzle opening **4**. The stopper **5** generally protects the core rod from losing its solidifying capacity before it contacts the fluid metal, and thus the core rod is retained at as low an energy level as practical so that its capacity for accretion of fluid metal by solidification from within is kept as high as is reasonbly possible.

When recycling is employed to deposit one layer of metal upon another, the quality of the previously deposited metal is improved, much as in fusion welding processes where one layer is deposited upon another.

The layer or layers of accretion metal are substantially free of lattice work dislocations, voids and incipient cracks or failures, and also of internal stresses.

The more perfect lattice work of the metal offers maximum resistance to applied energy from an external source since the bonding energy of the free electrons is at or near to its maximum. Any applied energy is more equally distributed throughout the crystalline latice work.

The atoms at the meeting surfaces between the core rod and the fluid column must be free to move into their natural place in the lattice work for bonding purposes. To facilitate this, it may be desirable to clean the surface of the solid state core as by grits blasting or ultrasonic means before it enters the hollow stopper to clean it of all oxides and surface impurities. If practical in a given instance it may be possible to enclose the entire operation in an inert or a deoxidizing atmosphere.

I claim:

1. The method of teeming and solidifying metals, comprising moving a solid state substantially unheated core rod of the metal at a continuous rate downwardly through a hollow tubular stopper in a tundish filled with fluid virgin metal and raising the stopper to form a tubular column of fluid metal flowing downwardly upon and embracing the rod in close contact therewith through a nozzle and with the outer surface of the column thereafter substantially free of confinement to expedite and facilitate the rapid escape of gaseous state impurities from the fluid state and instantaneous dropping of the energy level of the liquid state to that of the solid state as the rod and the column coalesce and fuse together in the progressive downward movement of the same, the principal solidifying action taking place from the inside outward toward the peripheral surface of the fluid state metal.

2. The method of claim 1, and thereafter repeating the cycle of operations recited to provide a solidified billet

substantially larger in diameter than the original rod and having the lattice work of the metal free from imperfections of the type obtained in normal ingot production.

3. The method of claim 1, and passing the moving column and core through a chamber flushed with an inert gas.

4. The method of claim 1, and passing the moving column and core through a vacuum zone.

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U.S. Cl. X.R.

117—114 A, 114 B, 114 C, 119, 128; 118—405; 164—86, 275

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,666,537 Dated May 30, 1972

Inventor(s) Sylvester V. Williams

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, the reference to the assignment should read:
assignor of 15% to Elwin A. Andrus, Milwaukee, Wis.

Signed and sealed this 5th day of December 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

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