Dec. 2, 1941. J. O. BETTERTON ET AL 2,264,287

METALLURGICAL PRODUCT AND METHOD OF MAKING SAME

Filed Jan. 18, 1939 3 Sheets-Sheet 1

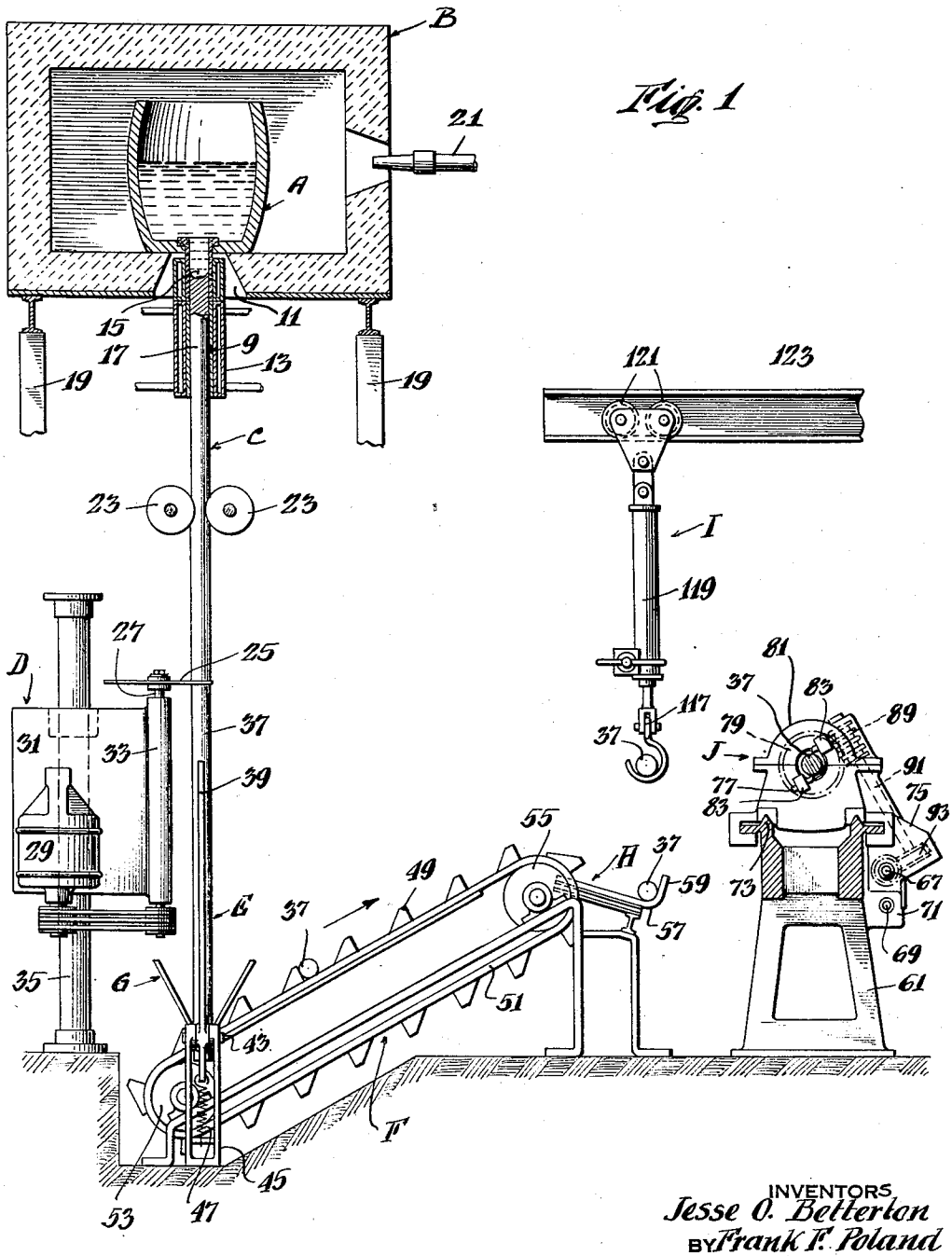


Fig. 1

INVENTORS
Jesse O. Betterton
BY Frank F. Poland
James K. Kent
ATTORNEY

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METALLURGICAL PRODUCT AND METHOD OF MAKING SAME

Filed Jan. 18, 1939 3 Sheets-Sheet 2

Fig. 2

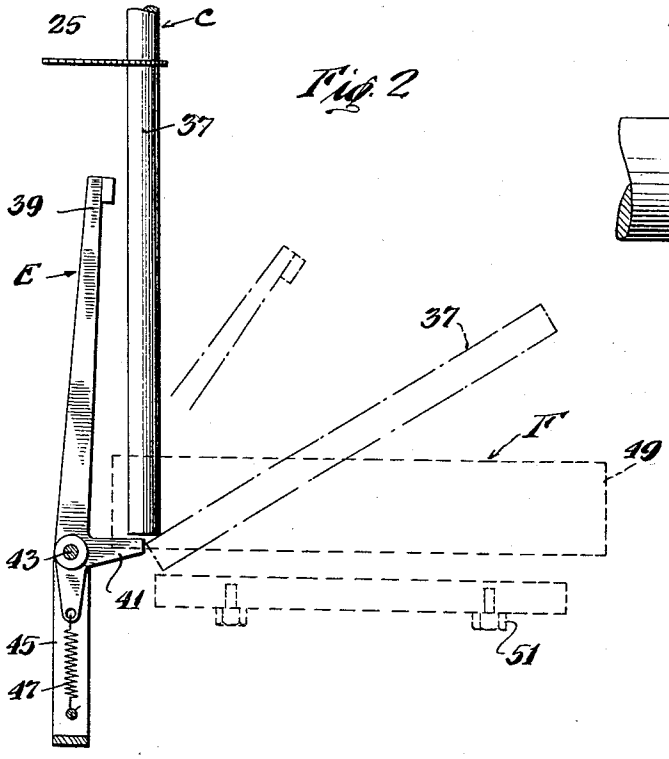


Fig. 7

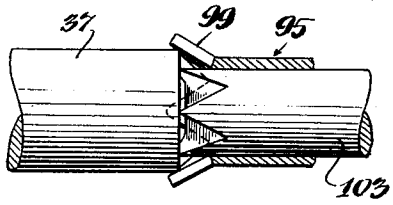


Fig. 6

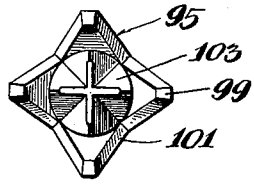


Fig. 5

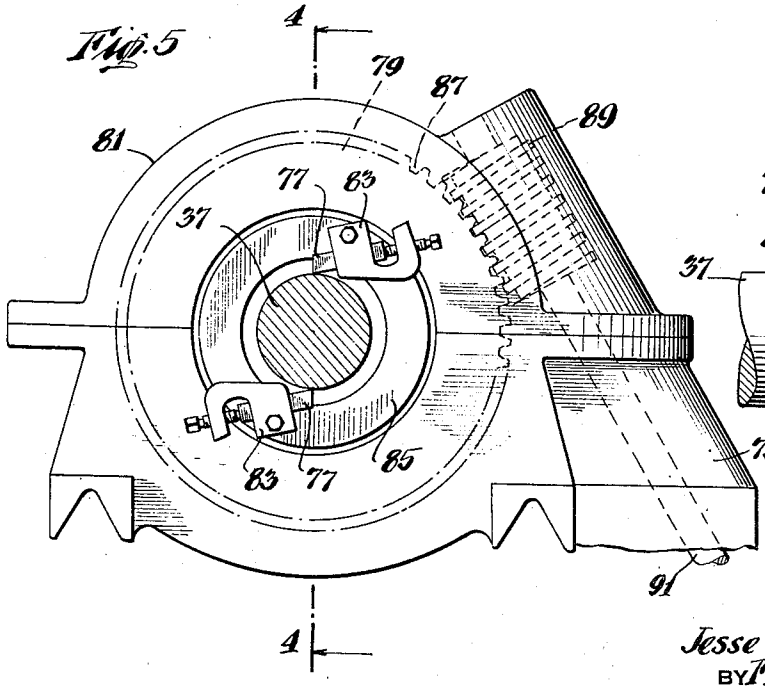
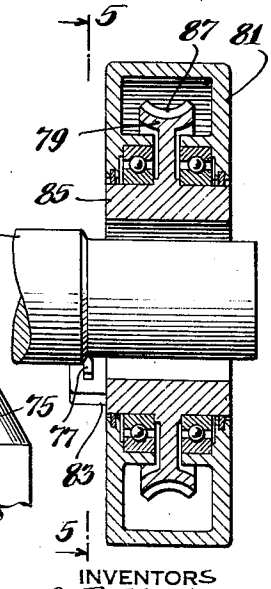


Fig. 4



INVENTORS
Jesse O. Betterton
BY Frank F. Poland
James R. Kent
ATTORNEY

Dec. 2, 1941. J. O. BETTERTON ET AL 2,264,287

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Filed Jan. 18, 1939 3 Sheets-Sheet 3

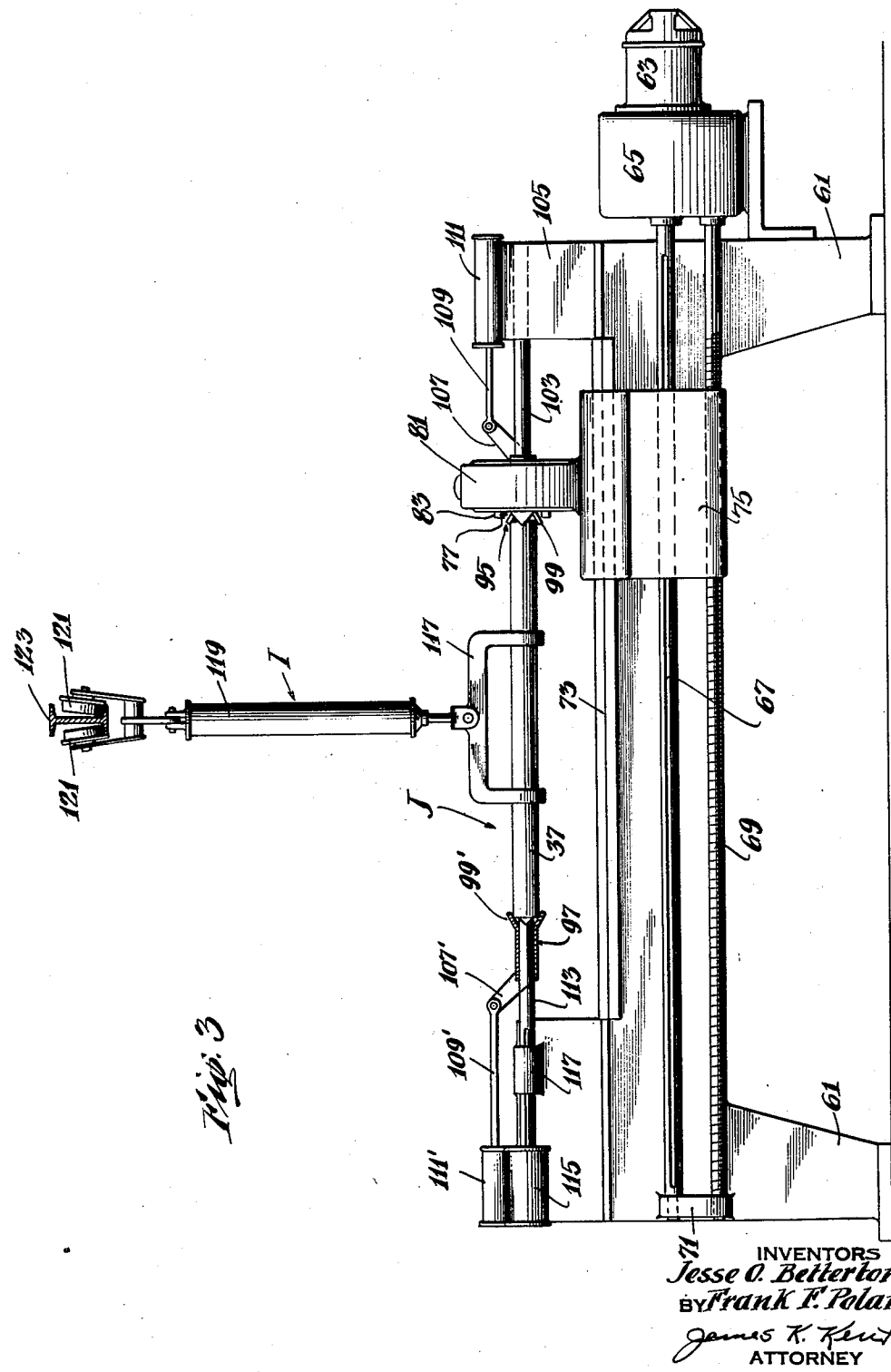


Fig. 3

INVENTORS
Jesse O. Betterton
BY Frank F. Poland
James K. Kent
ATTORNEY

Patented Dec. 2, 1941 2,264,287

UNITED STATES PATENT OFFICE

2,264,287

METALLURGICAL PRODUCT AND METHOD OF MAKING SAME

Jesse O. Betterton, Metuchen, and Frank F. Poland, Highland Park, N. J., assignors to American Smelting and Refining Company, New York, N. Y., a corporation of New Jersey

Application January 18, 1939, Serial No. 251,486

14 Claims. (Cl. 29—148)

The present invention relates to the production of seamless copper pipes or tubes wherein the tubes are produced by piercing a suitable copper billet on a rotary type piercing machine.

It is customary to produce seamless metal tubes by employing a machine in which a copper billet is forced against a piercing mandrel by the action of rollers which engage the billet and force it again the mandrel. Rotary piercing machines of the well known Mannesmann, Stiefel and other types are used customarily for this piercing operation.

The character of the tubing produced from copper billets is dependent to a very substantial extent upon the character of the billet, that is to say, the character of its surface, internal porosity, and the like, since the defects present in the billet are present likewise in the tubing produced therefrom.

The prior art of making these seamless tubes is open to improvements, at least some of which are included in the present improved process. In accordance with what has been recognized a standard practice of making seamless copper tubes, the following generally expressed procedure has been carried out:

1. A billet is cast by pouring molten copper into a vertical chilled mold. This copper may be oxygen-bearing copper, phosphorized-copper, or oxygen-free copper, all of which, however, are subject to limitations that do not produce an ideal billet. Such billets very commonly fall far short of perfection with respect to density, perfection of surface, and crystal size and orientation.

In the production of such billets, surface imperfections are an important cause of trouble; and it is to be noted in this connection that whatever imperfections are present in the billet, tend to persits throughout the entire fabrication and hence be found existent in the finished tube. Consequently, the condition of the billet becomes of great importance in the production of acceptable tubes.

The surface imperfections of the billet, noted above, may result from several causes. Thus, in casting the billet, it is necessary to use a mold dressing which is applied to the bottom and walls of the mold cavity. Such dressings as contain no volatile components are apt to be not adhesive to the mold and thus become included in the metal; also, slag and dirt may enter the mold during the top pouring, to form inclusions in the casting. On the other hand, where dressings are used which contain volatile components, the surface of the resulting billet may be improved, but the density of the billet may be poor through the presence of porosity in the billet.

These deficiencies of the recognized standard casting process have been known for a long time, and improvements have been made along certain lines, such as by improving the mold washes by utilizing as such an inert substance with which there are included a small amount of an adhesive and a small amount of a very volatile material which evaporates before casting. However, such provisions do not produce an invariable ideal billet, notwithstanding the very substantial advance made in the art by the utilization of such provisions in copper casting operations.

2. After the billet is cast and removed from the mold, it will be found, usually, that the upper ends of the billets are shrunken and defective. Such end usually is cut off in an effort to eliminate the most defective part of the casting; but in some cases this is not done.

3. The outside surface of the billet then is rough-dressed by chipping to remove slag inclusions, "cold sets" and other defects macroscopically present on the surface of the billet. However, it is not possible to remove internal imperfections which show up in the finished tubes as seams, slivers, or roughened areas on the inside surface of the finished tube and, accordingly, all tubes are subjected to a water test with water under high pressure, to find any leaks in the tubes resulting from the above-mentioned internal defects in the starting billet.

Therefore, there is required a very rigid hand inspection to detect slivers and laps on the inside of the tubes, since for many applications such as for mechanical refrigerators and for aeroplane use, the tubes must contain no imperfections as slivers are apt to break off in service and clog expansion valves and carburetor jets.

This close inspection is a matter of great expense, and additionally, there is a large amount of rejected material to add to the cost; and this inspection is so necessary and so important that bonuses have been paid to inspectors for each defect found, in addition to their regular pay.

4. After the billets have been rough dressed, in preparation for piercing to form a tube therefrom, one end of the billet is cupped and the billets are heated to from about 1400° F. to about 1600° F.

5. The billets while hot are pierced on a rotary piercing machine of one of the types previously mentioned above. Such machines comprise cooperating rolls of convex and concave shape, with intersecting axes, which impart a special forward motion to the billet being operated

upon. The angles and contour of the main rolls are so arranged that, as far as is practically possible, an equal speed is imparted to the billet at all points of contact between billet and rolls.

These rolls feed the billet against the piercing point or mandrel which is attached to a long shaft with bearings at the far end, mechanism being provided for retracting the piercing point or mandrel from the pierced billet. The rolls feed the billet onto the mandrel, there being no positive push on the mandrel, the rate of feed depending upon the mechanical arrangement of the machine and the chemical and physical characteristics of the billet.

As compared with the piercing of steel, copper is allowed more of a natural flow in the operation, the guide rolls being designed to allow this.

These guide rolls lie on the pass between the piercing rolls and vertically in line with the working center of the mill. The guide rolls are driven by the revolving of the billet during the piercing operation, and serve the double purpose of controlling the outside diameter of the shell and, in the case of the bottom roll, of overcoming the gravitating tendency of the billet to drop away from the piercing line of traverse. The importance of the functioning of the guide rolls will be realized by the fact that it is possible by their correct adjustments to produce four or more different diameters and wall thicknesses from the same sized solid billet, as for instance, 3¼ inches diameter solid may be pierced to produce shells from 4⅛ inches x 3⅝ inches down to 3¼ inches x 2⅝ inches, enabling the operator, within limits, to control the product of the machine in relation to any desired diameter and thickness of finished tube with a minimum of cold passes on the drawbench.

To turn now briefly to the piercing head or plug, referred to above as a piercing "point" or "mandrel," over which the material is spun, these again are designed so as to combine in conjunction with the rolls a piercing and rolling operation to produce a shell quite free from waves or ridges. There are two distinct angles, of which the rolling and planishing at the back of the body runs parallel with the 24° combined angle of the main rolls. In connection with the importance of maintenance of the design and position of the plug in the piercing process, it is important to point out that in the reduction of the solid billet on the inlet planes of the main rolls, a position is reached where its center or core is broken up, and it is therefore necessary to adjust the point of the plug to anticipate the fracture and so ensure a sound inside surface in the shell. In other words, if a billet is passed through the rolls set a suitable piercing adjustment, but without a plug, the result will be the production of a smaller bar with an irregular hole in its center.

A correct setting of the piercing plug theoretically prevents this disturbance of the center of the billet, so that the maintenance of the profile of the tool is an important factor in turning out good shells. The shank of the piercing mandrel is a fairly easy fit into the end of its supporting bar, the latter being either solid or formed of a steel tube of suitable diameter and thickness. The heel or back end of the piercing bar is carried in a gate arranged with a revolving socket, and with a center spindle allowing a lateral adjustment of 12 inches. On the length of the piercing bar are placed loose thimbles which are supported in a hinged outlet trough fixed on the bed or girder supporting the gate. The object of the thimbles is to prevent sagging or whip when the piercing bar is in compression during the piercing of the billets. Although opinion differs as to whether the piercing bar and plug should rotate or remain fixed during the process of piercing, it is evident that the resistance offered by the mandrel is reduced when allowed to revolve freely, and also that not only is the friction reduced, but the wear or distortion of the plug is considerably less in this case than when its position is a fixed one.

6. After the billet has been pierced, the resulting shell is subjected to cold drawings through steel dies with intermediate anneals to control grain size and physical characteristics of the finished tube. These operations vary in accordance with the size and physical specifications of the tubes.

It will be apparent from the above considerations that the character of the billet being pierced has a decided effect upon the kind of tubes that are produced therefrom. Thus, the billet must be free from internal porosity; its surface must be substantially free from imperfections; cracks in the metal must be absent; and, additionally, it has now been found that the crystal structure of the billet has important effects on the piercing operation. In this connection, it is noted that in piercing, the internal metal of the billet separates or splits ahead of the piercing mandrel, not at the mandrel, the copper flowing around the mandrel as the piercing proceeds; and it has now been discovered that if the billet has a definite crystal structure wherein the crystals are disposed predominantly inclined to the longitudinal axis of the billet in substantial accordance with the natural angle of clearance of the metal during piercing, internally perfect-surfaced tubes are more easily obtained than when the crystals are disposed parallel to the axis of the billet, or when the billet is composed of heterogeneously, or randomly, disposed crystals. This effect is found to be enhanced by feeding the billet to the piercing mandrel so that the piercing mandrel enters the angles defined between the inclined crystals; and it is noted that piercing the billet in the opposite direction tends to tear the interior surface of the finished tube.

Additionally, it is found that surface imperfections, cracks, and the like may be removed by machining the surface of the billet, which operation, additionally, improves the appearance of the billet, and renders it more acceptable to the trade.

From the foregoing considerations, it will become apparent that the present invention has for one of its objects the production of tubes that will be uniformly free from seams and internal defects, and which will have substantially mechanically perfect surfaces, both interiorly and exteriorly of the tubes.

A further object of the invention is to produce a billet of high density and of the proper crystal structure for the most effective piercing.

A still further object of the invention is to produce a billet of the above-indicated character which has removed therefrom surface imperfections of all kinds, and which has been machined to maximum smoothness that is commercially practicable, and free from macroscopic tools marks.

Further objects of the invention will become apparent as the description proceeds, and the

features of novelty will be pointed out in particularity in the appended claims.

It has been found, in accordance with the present invention, that copper billets produced by a particular kind of casting operation possess the requisite properties for the production of perfect tubes; especially is this found to be true where the billets are produced by continuous casting.

The concept of continuously casting nonferrous metals, such as copper and copper alloys by supplying the molten metal from a reservoir to one end of a die or mold having solid metal in the other end which serves as a plug and to which the molten metal welds as it solidifies, is indeed an old one and various and sundry processes have been proposed for its fulfillment.

In the copending application of Jesse O. Betterton and Frank F. Poland, Serial No. 86,600, filed June 22, 1936, for "Continuous casting," which issued April 2, 1940, as Patent No. 2,195,809, there are set forth in detail conditions and procedure which enable the process of continuous casting of copper to be carried out in a commercially practicable manner.

As has been pointed out in the above-identified copending application, continuous casting processes may be classified roughly with respect to the manner or method by which at least the major portion of the heat is withdrawn from the molten metal to effect its solidification as: (*a*) lateral cooling, that is, by extraction of the heat through the mold wall and (*b*) longitudinal cooling, that is, by extraction of the heat through the previously solidified copper. The above classification is based upon whether the major portion of the heat is extracted laterally or longitudinally in effecting solidification of the copper.

It has been found in practice that the continuous casting of copper at commercially practicable casting speeds is accomplishable only by laterally cooling the metal in the die at a rapid rate, and that this lateral cooling coupled with rates of production for commercial yields of cast metal produce a distinctly inclined or radial crystal structure in the cast metal, that is to say, the crystals of the cast metal extend from the center of the cast rod to the surface of the casting and terminate at the surface.

While observing the precautions set forth in the above-identified application and operating in accordance therewith, there is produced a very sound and high-density copper, the radial crystal structure of the metal produces a certain amount of surface irregularity caused by the ends of the crystals; also, as the casting operation proceeds, the opening through the die becomes worn gradually larger by action of the metal passing therethrough, the billets being cast thereby enlarging gradually in diameter.

For the conversion of these billets into fabricated articles or shapes, such as tubes, it is important for the surface of the billets to be as smooth and as perfect as possible when the billets reach the fabricator. It is found in practice that the sound, dense billets produced by continuous casting operations and with the radial crystal structure referred to above may be improved as to their surface, by subjecting the billets to a machining or "scalping" operation which imparts a machined finish to the surface of the billets, rendering them of mirror-smoothness and brightness, and also assuring their being machined to a uniform, predetermined diameter for the fabricator.

As has been pointed out in the aforesaid copending application, one of the important factors contributing to the successful operation of the continuous casting process lies in the treatment of the copper to degasify it preparatory to introducing it into the mold. Therefore, the copper is treated first in accordance with usual refining practice by blowing it with air until the hydrogen and sulphur are expelled as completely as possible and then poling the resulting low-set copper to a point where cast samples will have a density of at least 8.50. The resulting copper, though commercially gas-free, still contains a small amount of oxygen (less than 0.01%) and this is removed in any suitable manner as by incorporating small but sufficient amounts of a metallic deoxidizer therein. Phosphorus is an efficient deoxidizer and, if used, is preferably employed in a manner which imparts to the copper an approximate residual phosphorus content of from 0.001% to 0.005%. The copper so prepared being substantially gas-free, oxygen-free is now suitable for introduction into the mold, from which mold the solidified copper is adapted to be withdrawn in a continuous manner and directly transformed into the improved billets of the present invention.

The resulting product is a new product both from metallurgical and commercial aspects, which comprises copper containing 0.001% to 0.005% phosphorus, having a specific gravity of 8.93 at 20° C., or more (8.95 being common in practice) and possessing a radial crystal structure, that is, one in which the crystals are inclined in predominating numbers at an angle of at least 45° to the longitudinal axis of the casting, the billets having their surface provided with a machined finish and accurate predetermined diameter. Metallurgically, the product is a homogeneous, commercially sound phosphorus-deoxidized copper having a phosphorus content of 0.001% to 0.005% phosphorus, having a specific gravity of at least 8.93 at 20° C., of predominantly radial crystal structure as pointed out above, possessing an electrical resistivity of between 0.15436 and 0.15057 international ohm per meter-gram at 20° C. and possessing the ductility and softness of substantially pure copper.

Billets made from this copper by continuous casting operations retain of course these properties, and when the surface of such billets are finished by machining or "scalping" the fabricator has perfect metal upon which to operate, of high density, soundness and electrical conductivity.

The accompanying drawings illustrate one form of an apparatus which may be used in carrying out the invention, the views being rather diagrammatic in character; but it will be understood, however, that the invention may be carried out by various apparatus of quite different design and operation from that shown in the accompanying drawings, which are to be regarded, therefore, only as being illustrative, and in no way limiting in character.

In the drawings:

Fig. 1 represents a sectional elevation of equipment for producing, handling, and machining the billets.

Fig. 2 is a sectional elevational view of automatic means for transferring the billets as produced to the conveyor of Fig. 1, the view being taken on the line 2—2 of Fig. 1, looking in the direction of the arrows.

Fig. 3 is a side elevation of one form of milling

machine suitable for use in the machining operation.

Fig. 4 is a sectional elevation on an enlarged scale of the cutting or milling head, operating on a billet, one end of which is shown.

Fig. 5 is an end view of the tool head shown in Fig. 4.

Fig. 6 is an end view of one of the centering devices showing its relation to the cutting tools.

Fig. 7 is a sectional elevation of the same, showing one end of the billet in position thereon.

Referring more particularly to the drawings, A represents a reservoir for molten copper which has been treated as outlined above so as to render it gas-free, oxygen-free and with a phosphorus content of 0.001% to 0.005%, which copper is maintained molten by mounting the reservoir A in a furnace B which is heated by a suitable source of heat substantially above the melting point of copper. As casting proceeds, of course, the supply of copper in the reservoir is replenished from a suitable source, in accordance with the practice described in detail in the aforesaid co-pending Betterton and Poland application. The cast copper is represented by C, which is illustrated as issuing from the continuous casting apparatus as a rod of indefinite length, which is cut into billets of standard length, for example, 45 to 52 inches by means of sawing mechanism D. As the billets are sawed off, they drop successively into a striking lever E which pushes the falling billets onto a conveyor F by means of guides G, the billets being discharged from the conveyor onto a platform H. An air lift I removes the billets from the platform H and carries them to the "scalping" machine J.

The apparatus now will be described in greater detail.

The reservoir A is made preferably of graphite, this being an inert material with respect to copper and is provided with the casting mold or die 9, the reservoir A being mounted in the furnace B so that the die 9 projects through an opening 11 provided therefor in the bottom of the furnace A. The opening 11 is sufficiently large to admit a water jacket 13 which encloses the die 9 and through which water jacket a vigorous stream of water is circulated continuously for effecting solidification of the molten copper 15 in the channel 17 which extends longitudinally through the die and which forms the congealing chamber. The furnace B is heated by suitable means, such as a burner 21 and is shown as being mounted upon a suitable supporting structure 19. The cast rod passes between rollers 23 which control the speed at which the continuous billet rod C is withdrawn from the furnace, it being found in practice that at commercial casting speeds and with the major portion of the heat withdrawn radially from the rod, the cast metal possesses a distinctly radial crystal structure, the crystals extending radially from the center of the rod to the surface thereof. At least one of the rollers 23 is power driven from a variable speed motor (not shown) in well-known manner, so that the casting speed of the rod C is always under close control of the operators.

As the billet rod C is withdrawn from the die 9, it comes opposite the sawing mechanism D, which cuts the rod C into billets of desired length. This sawing mechanism need not be described here in minute detail, but it comprises a circular rotary saw blade 25 mounted on a shaft 27 which is driven from a motor 29, illustrated as being mounted on a panel 31, which also carries the housing 33 of the saw-driving shaft 27. The panel 31 is mounted on a standard 35 upon which the panel and saw assembly may be turned so as to move the saw blade 25 into and out of engagement with the billet rod C and also along which the panel may be moved longitudinally at a speed compatible with the speed of withdrawal of the rod C, so that the withdrawal of the rod need not be interrupted during the actual sawing operations.

As each billet 37 is cut off from the rod C, it falls upon the striking lever mechanism E. This mechanism comprises a lever arm 39 having a substantially right angled abutment 41, the arm 39 being pivotally fulcrumed at 43, adjacent to its lower end, to a supporting frame 45, the arm 39 being held normally in substantially vertical position by a tensioned spring 47 secured to the lower end of the arm 39 and to a cross pin or the like in the frame 45. The tension of the spring 47 holds the abutment 41 in the path of the falling billets, the impact of each billet causing the striking lever to turn on its pivot 43 against the tension of the spring 47, thereby impacting the lever 39 against the billet 37 as indicated in Fig. 2 so that the billet is knocked between opposing guides G which cause the billets to fall across the pushers of the conveyor F, these pushers 49 being mounted on spaced endless conveyor chains 51 which are passed around sprockets 53, 55 in the usual manner, which sprockets are driven from a suitable source of power, not shown.

The billets 37 are discharged from a conveyor onto a suitable receiving platform or table, indicated generally at H, the table proper 57 of which is formed of a pair of spaced rails, sloping downwardly to an abutment 59 which stops the movement of the billets 37 and enables the billets to be picked up by an air lift I of standard construction, which carries the billets to the finishing or "scalping" machine J.

This finishing machine is mounted on a supporting frame illustrated at 61, 61, this frame carrying a reversible motor 63 and speed reducer 65 by means of which are driven a splined driving shaft 67 and a feed screw 69, these extending the length of the machine, and having their ends remote from the drive mechanism supported in bearings indicated at 71. Slide rails 73 also extend along the side of the machine.

These slide rails 73 support an apron 75 which is moved along the machine by rotation of the feed screw 69, the apron 75 forming a protective covering for the drive mechanism for the cutting tool which will now be described. This cutting tool assembly is shown as comprising cutters, indicated at 77, 77, which are rotated around the billet by an annular gear 79 enclosed in a housing 81. The cutting tools 77, 77 are mounted in brackets 83, 83 which are united with the hollow hub portion 85 of the gear 79. The teeth 87 of the gear mesh with a worm 89, which is mounted on a shaft 91 driven by the drive shaft 67 through suitable gear connection indicated at 93. This driving mechanism for the cutters 77 are protected behind the apron 75.

In order for the cutting mechanism to operate on a billet 37, as indicated in Fig. 4, the billet must be aligned or centered properly. For this purpose, centering instrumentalities are provided which may comprise holding devices which are oppositely disposed relatively to each other and in exact alignment, these holding devices being indicated at 95 and 97, which have outwardly

flaring ends, 99, 99¹ in which the ends of the billet 37 are received. These ends 99, 99¹ are shown as being similar in shape to star drill points, and are fluted as indicated at 101 in Fig. 6 in order to clear the cutting tools 77, 77, as the milling heads 81 pass over the holders, as indicated in Fig. 3.

The holding device 95 comprises also a bar 103 which is slidably supported in bearing 105 at one end of the machine. This rod 103 and holding head 95 are moved outwardly and inwardly relatively to the bearing 105 by means of a lever 107 which is pivoted to the end of a piston rod 109 operating in a compressed air cylinder 111.

On the opposite end of the machine, the head 97 is mounted on a piston rod 113 of a hydraulic cylinder 115, a bearing 117 serving to support the piston 113 in position in aligned opposition to the bar 103. The piston 113 may be operated either by hydraulic pressure in cylinder 115 or through a lever 107¹ similar to lever 107, on the end of piston rod 109¹ operating in an air cylinder 111¹.

When it is desired to machine the billet 37, which is shown as being held in a holder 117 of the air cylinder 119 of the tilting mechanism I, the billet 37 is brought into position between the holding heads 95, 97 and air pressure is introduced in the air cylinders 111, 111¹ behind the pistons 109, 109¹ to move these outwardly towards each other until the ends of the billet 37 are engaged in the heads 95, 97 so that the billet is firmly held centered between these heads in position for the milling cutters 77, 77 to operate on the billet. Hydraulic pressure is introduced also behind the cylinder 115 so as to clamp rigidly the billet 37 in position during the machining operation.

The milling head 81 then is actuated, it being moved along the billet 37 by rotation of the feed screw 69, which in turn moves the apron 75 which carries the milling head 81, as has been described above. It will be understood, of course, that after the billet 37 has been positioned between the holding heads of the finishing machine it is released from the holder 117 which is adapted to be returned to the platform H for the next billet to be treated, the holder 117 and air cylinder 119 travelling on a trolley 121 operating on a mono-rail 123.

When the milling head and cutters have operated on the entire length of the billet, the motor 63 is reversed and the apron 75 and milling head are retracted to starting position for the succeeding operation by reversing the rotation of the feed screw 69. When the machining operation on the billet 37 has been completed, the billet is engaged by the air lift holder 117 and released from the finishing machine by retraction of the holding heads 95, 97 incident to relief of pressure in the cylinders 111, 111¹ and 115. The finished billet 37 is removed and the finishing machine is ready to receive the next billet to be treated.

In view of the fact that the continuous casting procedure produces extremely dense copper, as has been stated above, the finishing machining results in a perfect billet being available for fabrication into high quality seamless tubes. The finishing machining removes any surface irregularities due to the termination of the radial crystals and produces a billet of accurately predetermined diameter, removing as it does any variations in diameter arising during the casting procedure from wear on the die or from other causes. The metal being non-porous, the machining can expose no sub-surface pores, so that the machined surface is entirely smooth, free from pores and perfect mechanically. Moreover, the typical orientation of the crystals of the cast metal is not disturbed by the finishing machining operation.

The resulting product therefore is a machined copper billet with a substantially perfect surface, having a predominantly radial crystal structure, of commercial soundness, having a specific gravity of at least 8.93 at 20° C. or higher, which may by either pure copper or phosphorus-deoxidized having a phosphorus content between the limits of 0.001 and 0.005%, the said copper having an electrical resistivity of between 0.15436 and 0.15057 international ohm per meter-gram at 20° C., possessing the ductility and softness of substantially pure copper. It shows also a total loss in weight of less than 0.01% when heated in hydrogen for one and one-half hours at a temperature of 850°–900° C.

While phosphorus is the preferred deoxidant, other deoxidizing materials such as silicon, lithium, or calcium borides may be substituted therefor without departing from the scope of the invention, and not deleteriously effecting the physical properties of the product insofar as concerns its conductivity, density, radial crystal structure, and the like, so long as the critical limits of the residual deoxidizing elements retained in the copper are not exceeded.

In addition to operating in the specific manner as described above, the invention contemplates machining the surface of the copper as it issues from the casting apparatus, without cutting into billets subsequent to the machining operation.

It will be understood from the above description, that the term "radial" as applied to the crystal structure of the billets includes crystals which predominately in number extend from the longitudinal axis of the billet to the circumferential surface thereof, quite independently of any particular angle such crystals may make with the longitudinal axis of the billet. In practice however, such inclination will be, for the most part, between the angles of 90° and 45° to the longitudinal axis of the billet, and it is found that within this range, the piercing operations on the billet proceed the most expeditiously, particularly when the piercing mandrel enters into the angle defined between the crystals.

It has been found in practice also that the length of the individual crystals in the billet have a definite effect upon the annealing properties of the metal, after cold working, it being discovered that crystals above a certain critical length inhibit such properties, and the longer the crystals become, the more difficult it is to effect proper control of annealing process during the manufacture of the tubes; and it has been determined that the maximum limit of the length of the crystals imparting the best annealing properties to the metal is defined by $\sqrt{2}$ times the radius of the billet; and this relationship is obtained in practice by the manner of chilling the billet rod during casting and by maintaining the casting speeds of withdrawal above a minimum rate which is dependent upon the diameter of the rod being withdrawn, and which is experimentally determinable from that size.

It has been described above that the surface

of the billets is machined so as to render the billets of uniform diameter throughout and to produce a macroscopically smooth and mirror-bright surface, free from all irregularities, cracks, or other defects. Those skilled in the art of machining cast copper are familiar with the difficulty of obtaining a uniform appearance of the machined surface, on cast copper, because very small changes in the shape of the cutting tool and its angle of clearance and also the rate of feed of the billet will produce very characteristic surfaces, and it is now a requisite with the fabricators, since the introduction to the trade of the machined billets of the present invention, that the surface of the billets shall be uniform in appearance, macroscopically smooth and of a mirror brightness.

The difficulty referred to above regarding the change in surface appearance is not thoroughly understood as to its true origin or cause, but the appearance may be described best as a series of parallel lines similar in appearance to those observed on metallographic examination of cold worked metals (slippage lines) except in the case of the machined billets such lines on the surface are visible without a microscope, whereas the slippage lines referred to above require etching and high magnification to render them visible.

In order to minimize such surface lines, the present invention contemplates machining the billets with a particular kind of cut which both shears off the ends of the radial crystals of the billets and burnishes them, or co-works them, as the machining operation proceeds, thereby producing the uniformly smooth, mirror-bright surface referred to above; and in this connection, the radial crystal structure of the billets cause a more easy and uniform machining than is the case where the crystals are disposed longitudinally of the axis of the billet. In practice it has been found acceptable to machine the surface of the billet by applying a wave-like cut to the surface which may be considered to be somewhat generally similar to an elongated shallow Whitworth type thread cut.

A further property of continuously cast shapes in addition to their high specific gravity, is the high tensile strength of the shapes, this being of the order of 28,000 lbs./sq. in. or greater.

It will be understood, of course, that the finishing operations on the billet may be carried out otherwise than as has been described above, such as, for example, by broaching or lathing operations. Accordingly, it will be understood that the invention is not limited necessarily to the specific details of the process and construction as are herein specifically described, but it will be apparent that such details are subject to various modifications which will become apparent readily to one skilled in the art, without departing from the spirit of the invention; and it will be understood, therefore, that it is intended and desired to include within the scope of the invention such modifications and changes as may be necessary to adapt it to varying conditions and uses. It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described, and all statements of the scope of the invention, which, as a matter of language, might be said to fall therebetween.

What is claimed is:

1. In the art of producing seamless copper tubes by piercing copper billets, the improvements which comprise continuously casting a copper rod with radial crystal structure, cutting the rod into billets of predetermined length, and machining the surface thereof with a cutting tool which imparts a shearing and burnishing cut to the surface of the billet preparatory to piercing.

2. In the art of producing seamless copper tubes by piercing copper billets, the improvements which comprise continuously casting a copper rod while maintaining casting conditions of cooling and casting speeds favoring a radial crystal structure in the cast rod, cutting the rod into billets of predetermined length, machining the surface of the billets with a cutting tool which imparts a shearing and burnishing cut to the surface of the billet preparatory to piercing and piercing the billet on a piercing mandrel so that the mandrel pierces the billet by entering into the angles between the crystals.

3. In the art of producing seamless copper tubes by piercing copper billets, the improvements which comprise continuously casting a copper rod under conditions of cooling and casting speeds favoring formation of a radial crystal structure in the cast rod, cutting the rod into billets of predetermined length, machining the surface of the billets to remove any imperfections thereon, and piercing the billet by causing a piercing mandrel to enter into the angles between the crystals.

4. The method of producing deoxidized copper billets suitable for direct fabrication into tubes which comprises refining copper to a commercially gas-free, deoxidized condition, incorporting into the resulting copper a calculated sufficiency of phosphorus to completely deoxidize the copper and to leave a residual phosphorus content of not more than 0.005%, continuously casting the resulting copper in a manner insuring radial crystallization thereof, and machining the surface of the cast copper with a shearing and burnishing cut to render the said copper of a uniform predetermined diameter and to remove surface irregularities therefrom.

5. The method of producing deoxidized copper billets suitable for direct fabrication into tubes which comprises refining copper to a commercially gas-free, deoxidized condition, incorporating into the resulting copper a calculated sufficiency of phosphorus to completely deoxide the copper and to leave a residual phosphorus content of not more than 0.005%, continuously casting the resulting copper in a manner insuring radial crystallization thereof, converting the copper as cast into billets of pre-selected length, and machining the surface of the billets with a shearing and burnishing cut to remove surface irregularities therefrom and to render the billets of a uniform predetermined diameter throughout while preserving the radial orientation of the crystals of the copper.

6. A new metallurgical product for production of seamless copper tubing consisting of a continuously cast, round copper billet having a macro-crystal structure with crystals predominantly disposed at an angle to the longitudinal axis, the length of the said crystals not exceeding the product of $\sqrt{2}$ multiplied by the radius of the billet.

7. A new metallurgical product for the production of seamless copper tubes comprising a continuously cast, radially crystallized copper billet containing from 0.001% to 0.005% phos-

phorus, having a specific gravity of at least 8.93 at 20° C. with a surface machined and burnished to substantially mechanically perfect smoothness, the finished surface being free from pores, pits and any other imperfections.

8. A new metallurgical product for the production of seamless copper tubes comprising a continuously cast copper billet having a specific gravity of at least 8.93 at 20° C. and a predominantly radial crystal structure in which the majority of the crystals are disposed at least 45° to the longitudinal axis of the billet, the said billet having its surface machined and burnished to substantially mechanically perfect smoothness, the surface being non-porous and free from mechanical imperfections.

9. A new metallurgical product for the production of seamless copper tubes consisting of a continuously cast copper billet of commercial soundness with a specific gravity of at least 8.93 at 20° C., and a predominantly radial crystal structure in which the majority of the crystals are disposed at least 45° to the longitudinal axis of the billet, the said billet being composed of phosphorus-deoxidized copper having a phosphorus content between the limits of 0.001% and 0.005% while possessing an electrical resistivity not exceeding 0.15436 international ohm per meter-gram at 20° C. and exhibiting a total loss in weight of less than 0.01% when heated in hydrogen for one and one-half hours at a temperature of 850°–900° C., the said billet having its surface finished and burnished to substantially mechanically perfect smoothness and being adapted for direct fabrication into any desired final shape, the surface being free from pores and imperfections.

10. A new metallurgical product for the production of seamless copper tubes consisting of a continuously cast copper billet of commercial soundness with a specific gravity of 8.93 or more at 20° C., and a physical structure in which the crystals are disposed radially from the elongated axis of the casting to its surface, the said billet being composed of phosphorus-deoxidized copper having a phosphorus content between the limits of 0.001% and 0.005% while possessing an electrical resistivity of between 0.15436 and 0.15057 international ohm per meter-gram at 20° C. and possessing also the ductility and softness of substantially pure copper, the said billet having its surface finished and burnished to substantially mechanically perfect smoothness and being adapted for direct fabrication into any desired final shape, the said surface being non-porous and free from irregularities and imperfections.

11. A new metallurgical product for the production of seamless copper tubes consisting of a continuously cast copper billet having a specific gravity of at least 8.93 at 20° C. and being completely deoxidized copper, having a predominantly radial crystal structure in which the majority of the crystals are disposed at least 45° to the longitudinal axis of the billet, the said billet possessing an electrical resistivity not exceeding 0.15436 international ohm per meter-gram at 20° C. and exhibiting a total loss in weight of less than 0.01% when heated in hydrogen for one and one-half hours at a temperature of 850–900° C., and having its surface machine-finished, the said surface being mechanically perfect and free from pores.

12. In the art of producing seamless copper tubes by piercing copper billets, the improvements which comprise producing copper billets of radial crystal structure, machining the surface of the billets with a cutting tool which imparts a shearing and burnishing cut to the surface of the billet preparatory to piercing, and piercing the billet on a piercing mandrel so that the mandrel pierces the billet by entering into the angles between the crystals.

13. In the art of producing seamless copper tubes by piercing copper billets, the improvements which comprise producing copper billets of radial crystal structure, and machining the surface of the billets with a cutting tool which imparts a shearing and burnishing cut to the surface of the billet preparatory to piercing.

14. A new metallurgical product comprising a continuously cast, copper shape having a specific gravity of at least 8.93 at 20° C. and consisting essentially of copper with the crystals extending from the surface of the casting toward the longitudinal axis thereof in predominating numbers at an angle of at least 45°.

JESSE O. BETTERTON.
FRANK F. POLAND.