FIG. 5.
Our invention relates to the gravity casting of metals and alloys which, in the fused state, dissolve large quantities of gas or gases, such as air, oxygen, nitrogen, etc., and which quickly liberate the dissolved gas or gases during solidification. Such metals are exemplified by copper and silver. Such alloys are exemplified by copper-base alloys, such as copper-base bearing alloys. They are also exemplified by silver-base alloys.


Various copper-base alloys for casting are described in pages 662–680 of said "Mechanical Engineers' Handbook," and in "Cast Metals Handbook" published by American Foundrymen's Association. As stated in said "Mechanical Engineers' Handbook," such copper-base casting alloys are cast in sand, and it is impossible to cast pure copper in the foundry, and that, in casting copper, it is necessary to add deoxidizers such as silicon, magnesium, phosphorus, or zinc. According to our invention, we cast pure copper or copper mixed with deoxidizers. The copper-base casting alloys include tin bronze, leaded tin bronze, leaded brass, leaded yellow brass, aluminum bronze, leaded nickel brass, leaded nickel bronze, and silicon bronze.

Various copper-base bearing alloys, which we can cast according to our invention, are described in pages 665–670 of said "Mechanical Engineers' Handbook." They include bronzes which have 10%–20% of tin, lead-tin bronzes, copper-tin-lead bronzes, copper-tin zinc bronzes, copper-lead alloys, and aluminum bronzes. As stated in page 665, they can be cast by chill casting or sand casting.

It has been known for many years that it is difficult to cast copper and silver and certain copper-base alloys and silver-base alloys by gravity casting, due to the quick release of a large amount of dissolved air during solidification.

Various expedients have been proposed, because the failure to release dissolved gases quickly from the fused metal or alloy, results in entrapment of the gases in the solid casting or ingot, thus resulting in porosity and external recesses and irregularities.

It has been proposed to regulate the temperature at which the fused metal or alloy is poured by gravity into the mold; also to degasify the molten metal or alloy by adding a degasifying agent. In gravity casting, it has been proposed to vent the molds, and also to regulate the speed at which the fused metal or alloy is poured into the mold.

Porous sand molds have been used for many years. Such molds consist essentially of grains of quartz which are coated with a bonding agent and which are adhered to each other by said bonding agent. Such bonding agents are organic. As stated in page 1749 of said "Mechanical Engineers' Handbook," the surface tension of the metal is low, the molten metal penetrates the pores of a sand mold; and there is a serious disadvantage because the sand fuses and burns upon the fused metal. Such fusing and burning depends upon the bonding material, and on the presence of impurities in the sand, such as lime and feldspar, and also depends upon the size of the grains of sand. The fusing and burning of the organic binder contaminates the ingot or casting. In addition, a sand mold can be used only once, so that its use is expensive.

It has also been proposed to use molds which have integral walls, which are made of ordinary, non-porous, corrodible iron or corrodible steel, which also readily oxidizes at casting temperature. Molds which have integral walls, and which can be used in a plurality of casting operations, are designated in this field as permanent molds. Prior to each casting operation in an ordinary non-porous permanent mold, it is necessary to coat the face of the mold cavity with a release agent, such as powdered graphite or a graphite slurry. The resultant ingots or castings are full of holes, blisters and various surface imperfections. Also, objectionable oxides are formed on the surfaces of the castings or ingots.

In certain cases, the continuous casting process is effective for removing dissolved gases. However, the continuous casting process is limited to certain shapes of castings. Also, the continuous casting process requires expensive equipment. According to our invention, we can use simple gravity casting.

It has been proposed in British Patent No. 330,018 dated June 5, 1930, to use a permanent mold which has a porous wall which is made of sintered iron. Such iron is not resistant to corrosion or oxidation. In operating under said British Patent No. 330,018, it is necessary to coat the wall of the mold cavity with a chemical which releases gases under heat, such as bicarbonates, oxalates, borates, etc. We have had no experience which shows that the disclosure of said British Patent No. 330,018 is of no value in making a series of castings in a mold.

According to our invention, we provide a permanent mold, namely, a mold which has an integral wall, and which can be used to make a succession of good ingots or castings of the same quality, said ingots or castings being free or substantially free from porosity and surface defects. The metal or alloy is cast in direct contact with said integral wall, so that we eliminate any supplemental treatment, such as the application of a release agent.

Our invention is further explained in the annexed description and drawings.

Fig. 1 shows a bronze rod casting, which has been cast in an ordinary, non-porous, permanent iron mold. It shows the usual imperfections.

Fig. 2 shows two cast rods of bearing bronze, respectively marked 4 and 5. Said castings were made on a chilling plate which was made according to our invention. Said chilling plate was made of "316" stainless steel, having a pore size of thirty-five microns. These castings had no blisters, and were easily removed from the improved chilling plate.

Fig. 3 shows a cylinder C, which has a flat surface marked CF. This cylinder C was made of a porous alloy of iron and copper, which had 10% by weight of copper. Prior to casting, the pores of said cylinder C were filled with oil. Fig. 3 also shows respective bronze castings 6 and 7 which were cast on said flat surface CF.

Fig. 4 shows from left to right, five consecutive castings of copper-base alloy which were made successively in a "304" mold, which was made according to our in-
vention. No release agents were used. These five consecutive castings are of equal quality, and are free from pinholes and blisters.

Fig. 5 shows a section of a permanent mold 10, made of ordinary porous, corrugated iron, which does not embody our invention. Fig. 5 also shows consecutive bronze castings 11 and 12 made in said mold. The first casting 11 is of fair quality. The second casting 12 shows surface imperfections. Also, Fig. 5 shows particles of bronze adhering to the face of the mold cavity of mold 10, and clogging its pores.

According to our invention, the porous wall of the improved permanent mold is made of material which is non-corrosive and which is also non-oxidizable at the casting temperature, which may be 1200° C. to 1600° C. The casting temperature will depend upon the melting point of the respective metal or alloy.

Such material which we use for making the wall of the mold is exemplified by stainless steel, stainless iron, and graphite, and other non-siliceous material.

The minimum porosity of the wall of the mold is 15% by volume. A minimum porosity of 25% by volume is highly preferred, and the best porosity, in general, is 25% to 35% by volume.

The size of the pores of the wall of the mold cavity may be in a range of 5 microns, to 60 microns if the wall is made of stainless steel or stainless iron. The highly preferred pore size in said case is in a range of 12.5 microns to 25 microns. If the pore size is in said preferred range of 12.5 microns to 25 microns, the highly preferred porosity is said porosity of 25% to 35% by volume.

The porous wall of the mold cavity which is made according to our invention, has been tested for permeability to air at 20° C. to 30° C. In such test, a difference of air pressure of ten pounds per square inch was maintained at the opposed faces of said wall, and the thickness of the wall was one-tenth of an inch. Under such conditions, the flow of air through the porous wall was not less than 0.7 cubic foot per minute, per square inch of the area of the wall. Ordinarily, the thickness of the wall is 0.75 inch to 1.75 inches. This permeability to the flow of air under pressure decreases directly in proportion to increased thickness of the wall.

If the thickness of the wall is 0.75 inch, the minimum flow of air at said pressure of ten pounds per square inch, per square inch of wall surface is substantially 0.1 cubic foot per minute.

The improved mold is used without any coating of a release agent or a gas-forming agent, so that the fused metal or alloy contacts directly with the stainless steel or stainless iron or graphite or other material.

We thus prevent the fused copper or fused silver, or fused copper-base alloy or fused silver-base alloy from penetrating the pores of the improved mold by selecting its material, porosity, pore size, and permeability to air.

On the contrary, if an ordinary porous iron mold is used, the first casting clogs a considerable percentage of the pores of the mold. The second casting shows the usual imperfections, due to said clogging, and the second casting results in additional clogging. The third casting is as bad as any casting made in a non-porous iron mold. The use of an ordinary release agent is disadvantageous. Also, gas-releasing coating agents are useless in casting copper, silver, copper-base alloys and silver-base alloys which, in the fused state, dissolve large quantities of air and release said dissolved air upon solidification.

We have made tests by making bronze castings on chilling plates, in which the chilling plates had different chemical compositions.

In one test, the chilling plate was made of nickel, 99% pure. In another test, the chilling plate was made of "Monel," which is an alloy consisting of 67% of nickel, 30% of copper, 1.4% iron, 1% manganese, 0.15% of carbon, and 0.1% of silicon.

In other tests, the chilling plates were made of stainless, corrosion-resistant steel of various compositions; or stainless, corrosion-resistant iron of various compositions.

In these tests, said bronze alloys were at a temperature of 1200° C. to 1600° C. when said fused bronze alloys were poured on these chilling plates. Our tests showed that these fused bronze alloys adhered to the above mentioned chilling plates, except those which were made of various stainless, corrosion-resistant steels; or stainless, corrosion-resistant iron alloys.

We have tested porous molds which are made of various corrosion-resistant and non-oxidizable stainless steels, such as stainless steel "No. 304," stainless steel "No. 316." and the like. We have discovered that porous molds made of said corrosion-resistant and non-oxidizable stainless steels, and other corrosion-resistant stainless steels, or corrosion-resistant stainless irons, are different from corrodbale porous metals, in that walls made of porous corrosion-resistant stainless steels and irons completely released cast copper and silver, and also released alloys of copper and of silver, as exemplified by bronze bearing-alloys, without clogging the pores. An important factor is to use mold whose walls and pores are non-oxidizable.

We have also discovered that in using porous molds or chilling plates made of corrosion-resistant, stainless steels or corrosion-resistant, stainless irons according to our invention, it is unnecessary to use any release agent or any coating agent which gives up gas under heat.

Tests have shown that many perfect castings of copper, silver and their said alloys can be made in succession in the improved permanent porous molds made of corrosion-resistant stainless iron and corrosion-resistant, stainless steel, without any preliminary treatment of the casting surfaces of said porous stainless iron or stainless steel, and without use of any release agent or any gas-hardening agent. This also applies to chilling plates.

In general, we can cast any metal or alloy which substantially dissolves air when fused, and which releases the air with afterfurnace in the course of solidification.

We have also discovered that these unoxidized, corrosion-resistant, porous, stainless steel and stainless iron molds and chilling plates, have superior mechanical strength and that their pores can be cleaned, if so desired, by means of dilute mineral acids, such as nitric acid or sulphuric acid, without damaging the mold or changing its original pore size. On the contrary, porous molds made from ordinary iron or even chemically pure iron soon become rusty, and the rust or oxide clogs the pores, thus making impossible to release the entrapped gases of the solidifying metal or alloy. In endeavoring to remove the rust, by means of a suitable chemical agent, the ordinary corrodbale iron is also chemically attacked, and its original pore size is changed, which makes subsequent casting in such molds impossible. The original range of pore size must be accurately selected, and it should not be changed by use. The designation "stainless steel," whenever used herein, also covers "stainless iron." The terms "stainless steel" and "stainless iron," cover a large group of iron alloys, which do not corrode in contact with air. The classification of stainless steels or stainless iron is set forth in numerous publications and textbooks, such as "Engineering Metals and Their Alloys," by Carl H. Sammis, published in 1949 by The Macmillan Company, particularly in pages 602—625.

About forty of the corrosion-resistant iron alloys which are classified as "stainless steel" or "stainless iron," are listed as standard grades by the American Institute of Steel and Iron, with about 80 to 120 variations of said forty alloys. While these stainless steel or stainless iron alloys vary in composition, they all resist oxidation and corrosion in air at the casting temperature, and all con-
tain chromium. The grades of stainless steel or stain-
less iron are arranged in three groups or types by the
American Institute of Steel and Iron, known as "300," "400," and "500."

One type, designated as the "300" type, contains from
7 percent to 31 percent of chromium; from 8 percent
to 36 percent of nickel; from zero percent to 2 percent
of manganese; from zero percent to 3 percent of silicon;
from zero percent to 4 percent of molybdenum; and
from zero percent to 0.25 percent of carbon; and in
addition, some of the members of this "300" type or
group have very small quantities of sulphur, selenium,
copper, titanium, and columbium.

The "400" type of the classification of the American
Institute of Steel and Iron contains from 8 percent to 30
percent of chromium; no nickel with the exception of
three members of this group, each of which contains a
maximum of 2 percent of nickel; no manganese; no
molybdenum except that a few members of this group
have a maximum of 0.6 percent of molybdenum; carbon
from 0.1 percent up to 0.65 percent. A few members
of this group contain from 2½ percent to 8 percent of
tungsten.

The members of the "500" type or group, as classified
by the American Institute of Steel and Iron, contain from
4 percent to 6 percent of chromium, and no nickel.
When we refer to either "302" or "304" stainless steel,
we refer to a member of the "300" group.

Thus, "304" stainless steel has from 18 percent to 20
percent of chromium; 8 percent to 11 percent of nickel;
a maximum of 0.08 percent of carbon; a maximum of
2 percent of manganese; a maximum of one percent of
silicon; a maximum of 0.04 percent of phosphorus; a
maximum of 0.03 percent of sulphur; the balance being
iron.

As another example, the composition of "316" stain-
less steel, which is another member of the "300" group as
above mentioned, is 16 percent to 18 percent of chro-
mium; 10 percent to 14 percent of nickel; a maximum
of 0.10 percent of carbon; a maximum of 2 percent of
manganese; a maximum of one percent of silicon;
a maximum of 0.04 percent of phosphorus; a maximum
of 0.03 percent of sulphur; 2 percent to 3 percent of
molybdenum; the balance being iron.

One example of making a mold or chilling plate
according to our invention is stated below:

Example No. 1

The starting material was a powder made of "316" stain-
less steel. This powder was tested by sieves accord-
ing to the standard specifications for sieves of the United
States of America.

Substantially all of this powder passed through a No.
65 sieve, so that the particle size of substantially all of
this powder was less than about 0.210 millimeter.

About 3.5 percent by weight of this powder passed
through a No. 100 sieve, whose sieve opening is 0.149
millimeter.

23.6 percent by weight of this powder passed through
a No. 150 sieve, whose opening is about 0.100 milli-
meter.

24.7 percent by weight of this powder passed through
a No. 200 sieve, whose opening is 0.074 millimeter.

22.2 percent by weight of this powder had a particle
size just large enough to retain it in a No. 325 sieve,
whose sieve opening is 0.044 millimeter.

The remainder of said powder was of sufficiently small
particle size to pass through a No. 325 sieve.

This powder was first cold-pressed at a temperature of
20° to 30° C., under a pressure of 30 tons to 50 tons
per square inch, into substantially the desired final
shape of the mold. The cold-molded shape was then sintered
during a period of 30 minutes to 2 hours, at a tempera-
ture of 2100° F. to 2400° F., namely, at about 1170° C.,
under a hot-pressure or coining pressure of 30 tons to
50 tons per square inch, at said temperature of about
1170° C. This resulted in the finished mold. These
pressures can be varied, especially the hot-pressure or
coining pressure. The particle size of the powder can
also be varied.

In this example, the wall of the resultant mold may
have a porosity of 15 percent to 25 percent by volume,
depending upon the pressures used and the particle size
of the powder.

Of course a higher porosity and lower density can be
obtained by means of lower molding pressure; and lower
porosity and greater density can be obtained by higher
molding pressure. Particle size is also a factor.

The specific gravity of the wall of this mold can be
about 6.7, depending on the pressures used and the
particle size.

The mechanical strength increases with the density.

As a variation from the above, a mold was made
by using a "304" powder, in which substantially all the
powder had a particle size of substantially 0.149 milli-
meter, and by using suitable different pressures, a porosity
of 30 percent by volume resulted, in one case; and a
porosity of 35 percent by volume resulted in another
case.

We have also, by this method, made a porous chilling
plate made of stainless iron with a porosity of 30 percent
by volume; and a porous mold made of stainless iron
with a porosity of 18 percent by volume. We have found
that a porosity at low as 18 percent by volume is satisfac-
tory in many cases, although we prefer a porosity
of 25 percent to 35 percent by volume. The chilling plate
serves the same purpose as a mold.

It is important that the respective or individual pores
should not be too large, because large pores produce
a certain surface roughness, which makes it difficult to
remove the casting from the mold. A maximum pore
size of 0.0024 inch or 60 microns is therefore desirable.

This pore size depends, as one factor, upon the total
porosity by volume. For a selected porosity by volume,
the size of the pores can be also controlled by the par-
ticle size of the original powder, and the pressures which
are used, either cold-molding pressure or hot-coining
pressure.

Thus, if the respective metal body is to have a porosity
of 30 percent by volume, such body can be made with
pores of various selected sizes. As above noted, the size
of the pores may vary in a range of five microns to sixty
microns. As also previously noted, the preferable range
of pore size in a metal mold is substantially 0.0005 inch
to 0.001 inch, namely, 12.5 microns to 25 microns, with
a preferred range of porosity by volume of 25 percent
to 35 percent.

According to our invention, we can also use permanent
porous molds made of carbon or graphite, for casting
copper, silver and copper-base alloys and silver-base alloys
which rapidly release dissolved gas or gases during solidi-
fication. Metals and alloys other than the above have a
tendency to penetrate the pores of porous graphite, but
excellent castings of the above mentioned metals and
alloys can be obtained from such graphite molds without
using any release agent or other preliminary preparation.

The pore sizes of said graphite molds can be from 5
microns to 100 microns, but a pore size in the range of
5 microns to 50 microns is highly preferred. Also, even
more preferably, the pore size of the graphite molds
should be from 5 microns to 30 microns, in order to pro-
vide improved tensile strength and greater resistance to
wear.

These graphite molds have excellent thermal conduc-
tivity, which is almost equal to that of metal molds. Their
porosity may be 18% to 45% by volume.

The properties and manufacture of carbon and graphite
are well known, and are described, for example, in a
text-book entitled "Industrial Carbon" by Mantell, Sec-
ond Edition, published in 1946 by D. Van Nostrand Com-
pany, Inc. As stated therein, it is well known to use carbon and graphite molds for certain special casting work and for chills. Also, carbon and graphite products are normally porous with the porosity varying from 18% to 32%, but such porosity is not generally of any use, because the pores are irregular in shape and for the most part unconnected. The manufacture and properties and uses of porous carbon and graphite, which have connected pores and are suitable for use for the purposes herein is described in pages 349-353 of said "Industrial Carbon."

In general, in making such porous carbon or graphite, suitably sized, calcined petroleum coke particles are mixed with pitch binder. The mixture is molded into tubes, plates, leaves and dishes, and the molded shape is then baked to carbonize the pitch binder and to produce an integral structure. Porous graphite is then made by graphitizing the amorphous carbon material. Hence it is not necessary to describe the manufacture of the graphite molds which we use. Such porous carbon or graphite has been previously used for filtration, aeration, and diffusion. As stated in page 349 of said "Industrial Carbon," the average air permeability of such porous carbon and graphite, at 70° Fahrenheit, if the air has 15% humidity, in a sample which has a thickness of one inch, varies from 4 cubic feet to 33 cubic feet per minute per square foot, under a pressure of two inches of water. As stated in page 350 of said "Industrial Carbon," the effective porosity of such porous carbon and graphite is 48%, and the average pore diameter is 33 microns to 190 microns.

However, porous carbon or graphite which is permeable to air and has connected pores has not hitherto been used in the gravity casting of metallic materials which are exemplified by copper, silver, copper-base alloys and silver-base alloys, which quickly release large amounts of dissolved air upon solidifying.

It has been proposed in Traenker, U. S. Patent No. 2,618,032 to use certain porous molds, including graphite molds, but the pores of such molds have been clogged or closed by colloidal graphite. We use molds which have uncoiled pores and which are permeable to air.

At stated in page 352 of said "Industrial Carbon," porous carbon has a capillary or wicking action, so that it would ordinarily be considered that such material would be wholly unsuitable for the purposes herein, in which capillary or wicking action is wholly undesirable, since the molten metallic material should not enter the pores and clog them upon solidification.

In general, our method applies to metals and alloys which blister upon solidification. Thus, in the first stage of producing copper from cuprous oxide and cupric sulfide, the copper is poured into molds and solidified. Such copper is designated as "blister" copper, because large blisters or bubbles are formed by escaping gases when the copper solidifies.

According to our invention, we cast such blistering metals and alloys against an integral, porous wall which is made of non-siliceous material and which is inert to the fused metallic material, and which does not exert any capillary, clogging effect on the fused metallic material, and we cause the escaping gases to flow sufficiently through the uncoiled pores of said porous wall to prevent any substantial internal porosity and to prevent any substantial surface blistering.

One example of a typical casting (but not limited thereto) is a bronze rod which diameter is one inch to six inches, and whose height is twelve inches to forty-eight inches. This is cast by gravity in a mold of the above shape, said mold having a mold cavity which is open only at its top.

In such case, we can make a solid bronze rod casting in which there is no substantial surface depression due to gas.

If such a rod is cast in an ordinary mold, the depth of such surface depression may be up to one-fourth inch, and about 4 percent to 25 percent of the diameter of the rod.

Whenever the word "air" is mentioned herein, it is intended to refer to any other gas.

We claim:
1. A permanent mold for gravity-casting fused metallic material of the class of copper, copper alloys, silver and silver alloys which normally blisters during solidification, said mold having a mold cavity which has an integral and bare porous wall made of material selected from a class which consists of stainless steel, stainless iron and graphite, said mold being made of non-corrodible material which is non-oxidizable at the casting temperature; said wall having uncoiled pores which have a size of five microns to one hundred microns, said wall being sufficiently permeable to air to permit the free passage of gases, which are released from said fused metallic material upon solidification thereof and to form a substantially blister-free casting, said uncoiled pores being sufficiently fine to prevent the entry of said fused metallic material into said uncoiled pores, said wall having a porosity of 15% to 35% by volume, the material of said wall being sufficiently permeable to air at 20° C.–30° C., under an air pressure of ten pounds per square inch and at a wall thickness of 0.1 inch, to pass a minimum of 0.7 cubic foot of air per minute, per square inch of the area of said wall material.

2. A method of casting fused metallic material which dissolves air or gas in the fused state and which releases the dissolved air or gas rapidly upon solidification, which consists in casting said fused metallic material by gravity in a mold defined by a permanent porous wall fabricated from a non-corrodible and inert material selected from the group consisting of stainless steel, stainless iron and graphite, said walls having pore sizes of from 5 to 60 microns for stainless steel and stainless iron and 5 to 100 microns for graphite and being sufficiently permeable at 20° C.–30° C. and under a pressure of ten pounds per square inch and at a wall thickness of approximately 0.1 inch, to pass a minimum of 0.7 cubic foot of air per minute per square inch of wall surface.

3. A method according to claim 2, in which the released air or gas is passed through said porous wall with sufficient rapidity to prevent the formation of any substantial surface depression in the solidified metal casting.

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