METHOD OF FORMING MAGNESIUM INGOTS FOR WORKING

Filed June 4, 1929

Fig. 1.

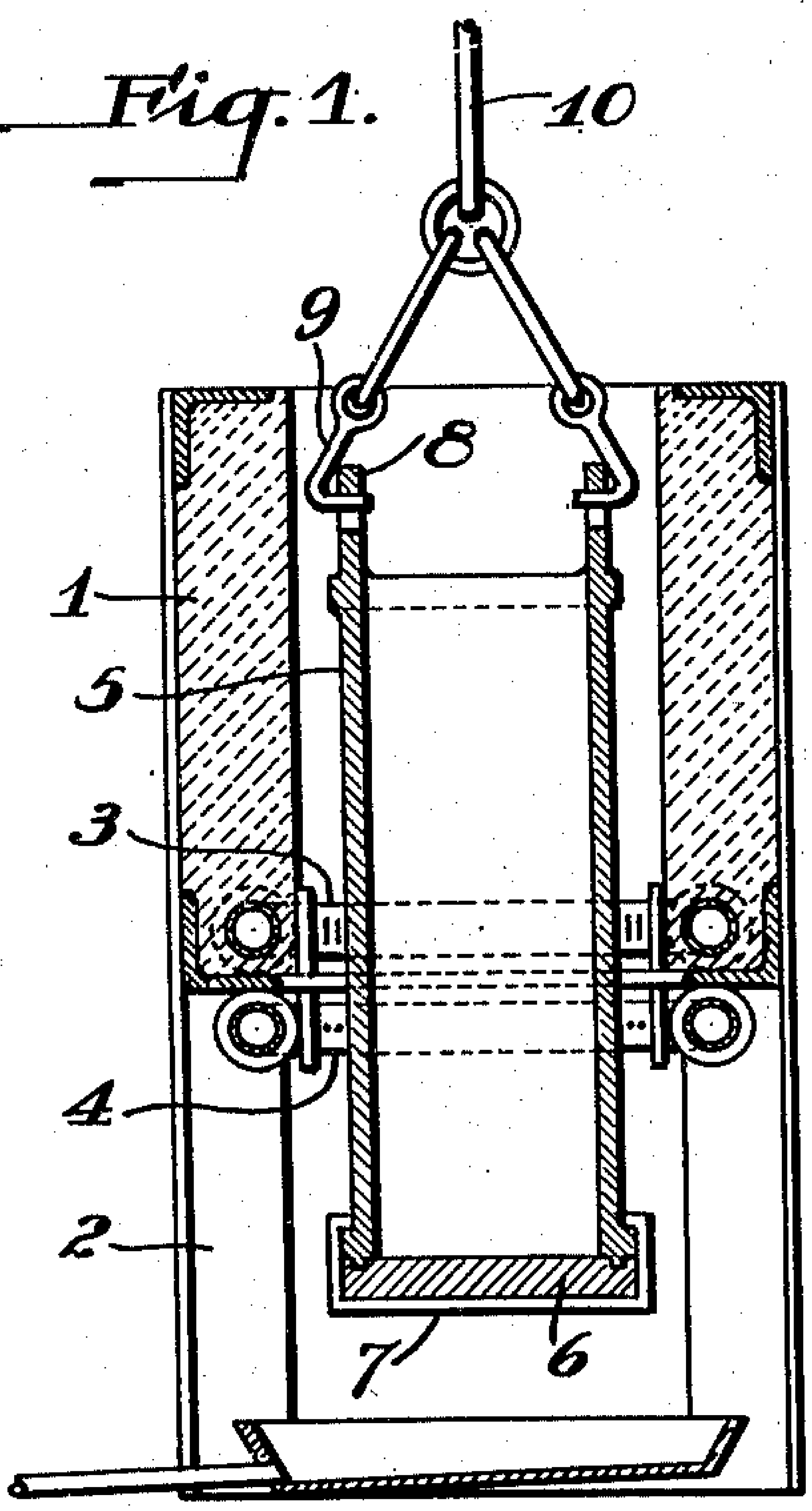


Fig. 2.

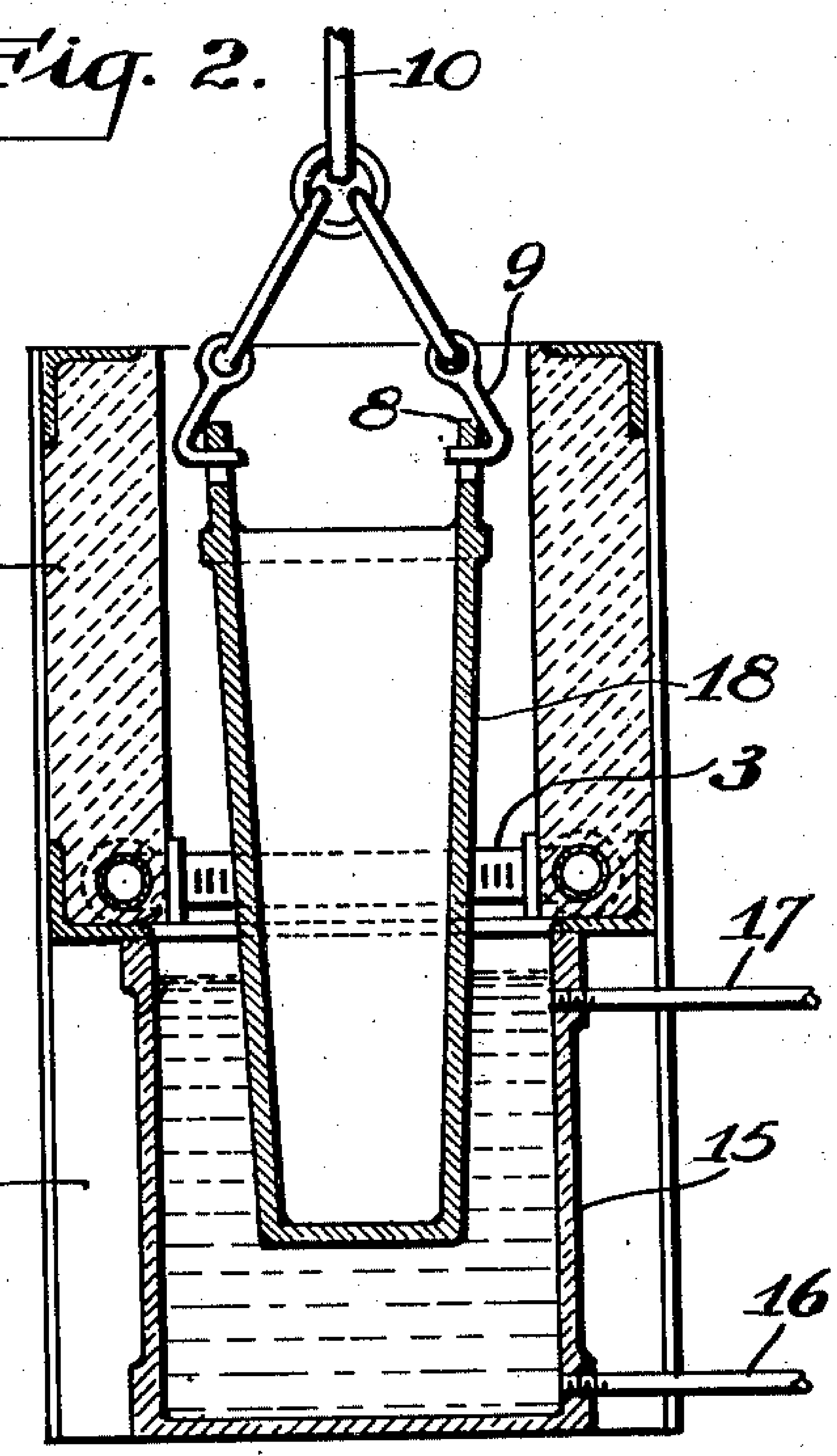
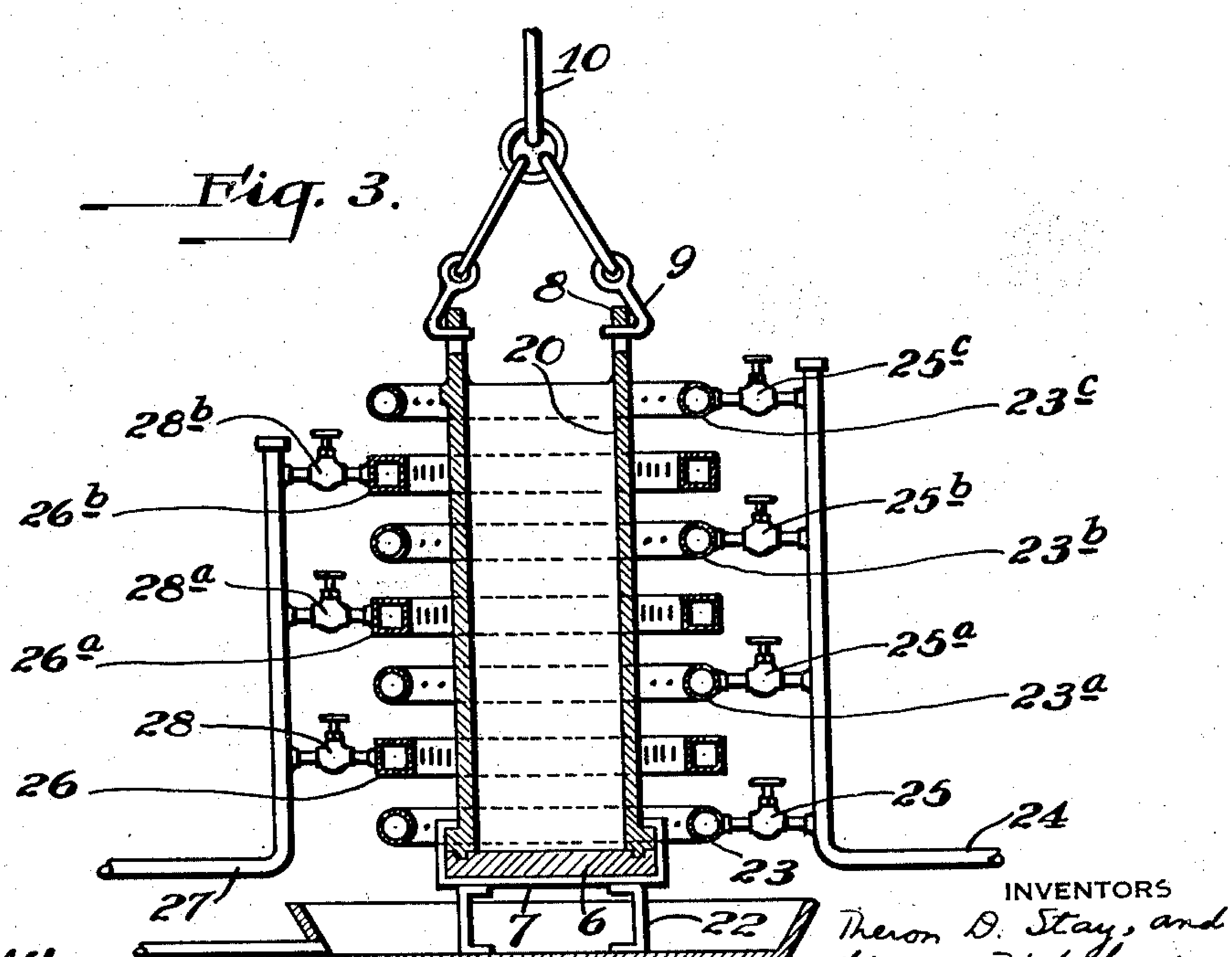


Fig. 3.



WITNESS
A. B. Wallace.

INVENTORS
Theron D. Stay, and
William Holzhauer
by Brown & Critchlow
their attorneys.

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UNITED STATES PATENT OFFICE

THERON D. STAY, OF CLEVELAND, AND WILLIAM HOLZHAUER, OF LAKEWOOD, OHIO, ASSIGNORS TO AMERICAN MAGNESIUM CORPORATION, OF NIAGARA FALLS, NEW YORK, A CORPORATION OF NEW YORK

METHOD OF FORMING MAGNESIUM INGOTS FOR WORKING

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The invention relates to the formation of ingots of magnesium and magnesium base alloys, which ingots are subsequently worked by rolling, forging, extrusion, and the like.

The fabrication of magnesium and magnesium alloy objects from ingots has been attended by numerous difficulties due largely to the unsatisfactory character of ingots. Not only is it desirable to avoid piping, which necessitates cropping and corresponding scrap loss, but the ingots should be free from porosity, which, as is well known may cause defects in the finished article. In addition, in the case of magnesium base alloys, liquation and segregation should be avoided because of their prejudicial effect upon the working properties of the ingots and upon articles produced from them. These considerations apply to most metals and alloys, but it is more difficult to produce satisfactory ingots of magnesium and magnesium base alloys because when molten they are highly reactive to moisture, oxidizing agents and the constituents of the atmosphere. Also, because of the low specific gravity of magnesium, the ingots are more likely to contain larger amounts of oxide and other non-metallic impurities, and to be more porous than other less readily oxidizable metals and alloys.

Furthermore, in producing metal ingots for working, it is desirable to provide a grain structure throughout which best meets the requirements of the particular manner of working to which they are to be subjected, and such as will result in good physical properties of the worked metal. A particular difficulty in the fabrication of ingots of magnesium and magnesium base alloys resides in their tendency to surface and corner cracking upon being worked, this being in general more pronounced than in most other metals. As far as we are aware, the grain structure of magnesium ingots has not heretofore been controlled to avoid these difficulties.

It has heretofore been observed that metal ingots of improved character in some respects can be produced by progressively cooling the molten metal from the bottoms of the ingot molds upwardly, either by gradually lowering the molds into bodies of water, or by spraying water upon the molds, beginning at the bottom and advancing the spray upwardly, or moving the molds downwardly through the spray. As compared with natural cooling, this practice results in the formation of ingots in which piping is materially reduced, the tendency to liquation and segregation is lessened, and porosity due to gas occlusion and to shrinkage is diminished. While these procedures improve the grain structure, nevertheless the ingots have grains of irregular size and dendrite forms extending upwardly and inwardly from the outer faces to the centers of the ingots. Such a structure does not wholly overcome corner and surface cracking, and it does not lend itself to attainment of the best physical properties in the worked metal.

The object of our invention is to provide a method of forming magnesium and magnesium base alloy ingots for working, the ingots having such grain structure and such freedom from segregation, liquation, and porosity, that the worked metal has high and uniform physical characteristics and does not develop surface cracks and corner cracks while being worked.

Our invention is predicated on our discovery that its stated object is attained by progressively, gradually and rapidly solidifying a body of molten magnesium or magnesium base alloy in an ingot mold from its bottom to its top while applying heat to the unsolidified portion of the metal about its progressively rising plane of solidification.

In the practice of our invention as applied to the formation of magnesium or magnesium base alloy ingots for working, an ingot mold of suitable form is supplied with molten metal at a temperature best suited to the formation of the desired grain structure of the solidified ingot, the metal being poured into the mold in a careful manner so as to preclude any large amount of splashing of the metal and thereby avoid consequent formation of oxide and nitride occlusions and the development of other prejudicial characteristics. The metal in the mold is then progressively and gradually solidified from the bottom to the top of the mold while heat is applied to the body of the metal above its progressively rising plane of solidification. Such solidification of the metal may be accomplished by gradually lowering the mold through a burner or series of burners which apply heat to its walls to keep the upper portion of the metal molten and at its desired temperature, and through a spray or sprays of water applied to the mold below the burners to progressively cool the metal substantially in that portion of the mold lying in the horizontal plane passing through the spray. In a similar manner, the mold may be gradually lowered through a burner or burners into a body of water below the burner, the body of water being used instead of spraying water upon the mold. As a further alternative, the mold may remain stationary within a series of alternating water sprays and burners which are individually controlled to cause the metal to progressively solidify in a gradually rising general plane while being maintained molten above such plane. While gas or other fluid fuel burners are preferably used for heating the upper portion of the mold and its contained metal, it will be understood that such heating may be effected electrically or otherwise.

Apparatus which may be and has been used in the practice of the invention in the several ways just explained is illustrated in the accompanying drawings, of which Fig. 1 is a vertical central sectional view of a mold passing downwardly through a heater and a water spray; Fig. 2 a similar view of a mold passing downwardly through a heater and into a body of water; and Fig. 3 a similar view of a stationary mold surrounded by alternately arranged burners and sprays.

The apparatus shown in Fig. 1 comprises a vertically disposed shaft 1 of refractory material suitably supported by posts 2 and provided at its bottom with a gas or other fluid fuel burner 3 preferably extending on all sides of the shaft. Below burner 3 there is a spray pipe 4 which also preferably extends on all sides of the shaft, or in other words, completely surrounds the mold. In the course of being lowered through the superposed heater and cooler, there is an ingot mold here shown as consisting of a tubular side wall member 5 which is preferably square in cross section, and a removable bottom 6 attached to the side wall member by straps 7, the lower edge of the wall being suitably luted in a groove formed in the upper face of the bottom 6. The top of the mold is provided with lugs 8 engaged by hooks 9 attached to a cable 10 which is paid out at a predetermined rate by means of any of the various well known mechanisms for doing this. As the mold is lowered through cooling spray 4, the metal in the mold solidifies in a general plane lying substantially in that of the spray, and the metal above this plane of solidification is maintained in its molten condition by heat from burner 3, the flames of which rise between the wall of the mold and shaft 1.

The apparatus shown in Fig. 2 is similar to that of Fig. 1, the water spray 4 of Fig. 1 being displaced by a vessel 15 provided with a body of water, which, if desired, may be circulated and kept at a definite horizontal level by means of inlet and outlet pipes 16 and 17. The mold 18, shown in Fig. 2 as being lowered through the heater and into the cooler, is of the closed bottom integral type, and may be suspended and lowered in the same manner as explained with reference to Fig. 1.

In the apparatus shown in Fig. 3, a mold 20 of the same form as that shown in Fig. 1 is indicated as resting upon a base 22, and as being surrounded by a series of water spray pipes 23, 23ª, 23ᵇ and 23ᶜ, each connected to water supply line 24 from which flow of water to each of the several spray pipes is independently controlled by valves 25, 25ª, 25ᵇ and 25ᶜ. Between adjacent water spray pipes there are burners 26, 26ª, and 26ᵇ, each connected to a fuel supply pipe 27 from which flow of fuel is independently controlled by valves 28, 28ª and 28ᵇ.

In the operation of the apparatus of Fig. 3, a valve 25 is first opened to cause water to spray from pipe 23 upon the lower portion of the mold, and burner 26 is lighted to maintain molten the metal in the upper portion of the mold. At the beginning of the cooling operation sprays 23ª, 23ᵇ and 23ᶜ are not used, but where necessary the upper burners 26ª and 26ᵇ may be used, this being determined by a suitable pyrometer placed in the molten metal. As the plane of solidification of the metal rises, burner 26 is turned off by closing valve 28, and spray 23ª is brought into play by opening valve 25ª, burner 26ª being then lighted if not previously in use. This procedure is followed until the rising plane of solidification reaches the top of the metal in the mold. In the use of this apparatus heat is effectively abstracted from the molten metal through the lower solidified portion of it and through the lower cooled portion of the mold wall, and accordingly in some cases, depending upon the size of the ingot being solidified, it is unnecessary to use the upper sprays and burner or burners.

A substantial advantage in the use of the spray cooling apparatus of Figs. 1 and 3 is that the ingots may be formed without taper from end to end. When spray cooling is used, open bottom molds having parallel side walls as shown may be employed without liability of water obtaining access to the molds at their bottom joints. By removing the bottoms the side walls of the molds may be stripped from the solidified ingots, either by a hammer or a press if shrinkage has not been sufficient to permit the mold to readily strip from the ingot. When the metal is cooled by lowering the molds into the body of water in the manner illustrated in Fig. 2 it is usually necessary to use closed bottom ingot molds, which, in order to assure the removal of ingots from them, must be tapered outwardly from their bottoms to their tops, as illustrated.

From the foregoing description of the construction and operation of the apparatus which may be, and which in point of fact has been, used in the practice of our invention and in the attainment of its object, it will be noted that the gradually rising plane of solidification of the metal is not a geometrically true plane, this term being used in the specification and in the claims to describe and define a solidification stratum which is flat as compared to the prior somewhat conical solidification strata incident to the solidification of metal proceeding from the side walls as well as the bottom of a mold. The chilling of the mold at and below the point of application of a cooling medium being rapid, and the mold being maintained at an elevated temperature above the plane of application of the cooling medium, the metal in the mold above such plane does not chill upon the upper side wall of the mold, and accordingly upwardly and inwardly extending elongate dendrite crystallization of the metal is precluded.

In the practice of each of the several described ways of progressively cooling the metal various advantageous grain structures may be produced. By maintaining that portion of the metal above the rising plane of solidification at a temperature materially higher than its melting point, we have found that the grain structure is of an elongated form extending parallel to the vertical axis of the ingot, which is in the direction of working of metal by rolling. By maintaining, as is preferred, the unsolidified portion of the metal at a temperature slightly above its melting point, there results an ingot having a fine equiaxed grain structure substantially uniform from end to end, and which may be forged or otherwise worked without developing corner and surface cracks. It is inherent in both of these procedures that the metal solidifies simultaneously throughout its substantially horizontal rising plane of solidification, as distinguished from solidifying progressively from the wall of a mold towards the center of the metal in it, such simultaneous solidification being due to the continual and uniform extraction of heat by and from the solidifying metal which is beneath the molten metal. Also ingots formed by both of these procedures have substantially uniform compositions throughout.

As a specific example of the practice of our invention in the formation of ingots having fine equiaxed grain structures, we have found that in forming ingots 8 x 8 x 24 inches from magnesium of commercial purity, and by the use of the apparatus of Fig. 1, fine equiaxed grain structure, coupled with freedom from porosity and piping, are produced by lowering the ingot mold at a rate of about ¾ of an inch per minute while spraying on it from 15 to 20 gallons of water per minute, and while maintaining the unsolidified metal at a temperature of about 1250° F., the mold having been filled with metal at an initial temperature of about 1300° F. In like manner there may be produced ingots of magnesium base alloys, which, in addition to having the foregoing characteristics, are substantially free from segregation and liquation.

The benefits of this invention arise in part from the provision of ingots of magnesium or magnesium base alloys, in which piping and porosity are largely eliminated, and which are also of improved quality due to the opportunity given the ingots to scavenge themselves on non-metallic impurities. Furthermore, in the case of magnesium base alloys, segregation and liquation are substantially eliminated. A marked advantage of these ingots arises from their greatly improved grain structure resulting in improved working characteristics by the elimination of surface and corner cracking. The superior qualities of metal worked from these ingots becomes apparent by comparison of the physical properties of the worked metal with those of metal of the same composition worked from ingots having the coarser grain structures and less desirable ingot characteristics consequent upon the formation of ingots according to the prior practice. Specifically, the tensile strength and elongation of the worked metal are superior to those of the same metal made from ingots formed according to prior practice.

Because the invention is applicable to both magnesium and magnesium base alloys, the term "magnesium" is used in the claims to collectively define both.

According to the provisions of the patent statutes, we have explained the principle and mode of operation of our invention, and have given specific directions concerning the manner of practicing it. However, we desire to have it understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically described, and with the use of apparatus other than that illustrated.

We claim as our invention:

1. The method of forming in a mold from a molten body of magnesium an ingot for working having a readily workable grain structure and of substantially uniform com-

position throughout, comprising solidifying said body in and simultaneously throughout a substantially horizontal plane rising gradually and progressively from the bottom to the top of the body of metal, and maintaining in its molten condition the portion of the body of metal above its said rising plane of solidification.

2. The method of forming in a mold from a molten body of magnesium an ingot for working having a fine equiaxed grain structure and of substantially uniform composition throughout, comprising solidifying said body in and simultaneously throughout a substantially horizontal plane rising gradually and progressively from the bottom to the top of the body of metal, and maintaining at a temperature slightly above its freezing point the portion of the body of metal immediately above its said rising plane of solidification.

3. The method of forming in a mold from a molten body of magnesium an ingot for working having a grain structure of elongated form extending parallel to the vertical axis of the ingot as formed and of substantially uniform composition throughout, comprising solidifying said body in and simultaneously throughout a substantially horizontal plane rising gradually and progressively from the bottom to the top of the body of metal, and maintaining at a temperature materially higher than its freezing point the portion of the body of metal above its said rising plane of solidification.

In testimony whereof, we hereunto sign our names.

THERON D. STAY.
WILLIAM HOLZHAUER.