Oct. 7, 1930. T. D. STAY ET AL 1,777,657

METHOD OF FORMING INGOTS FOR WORKING

Filed Feb. 11, 1929

Fig. 1.

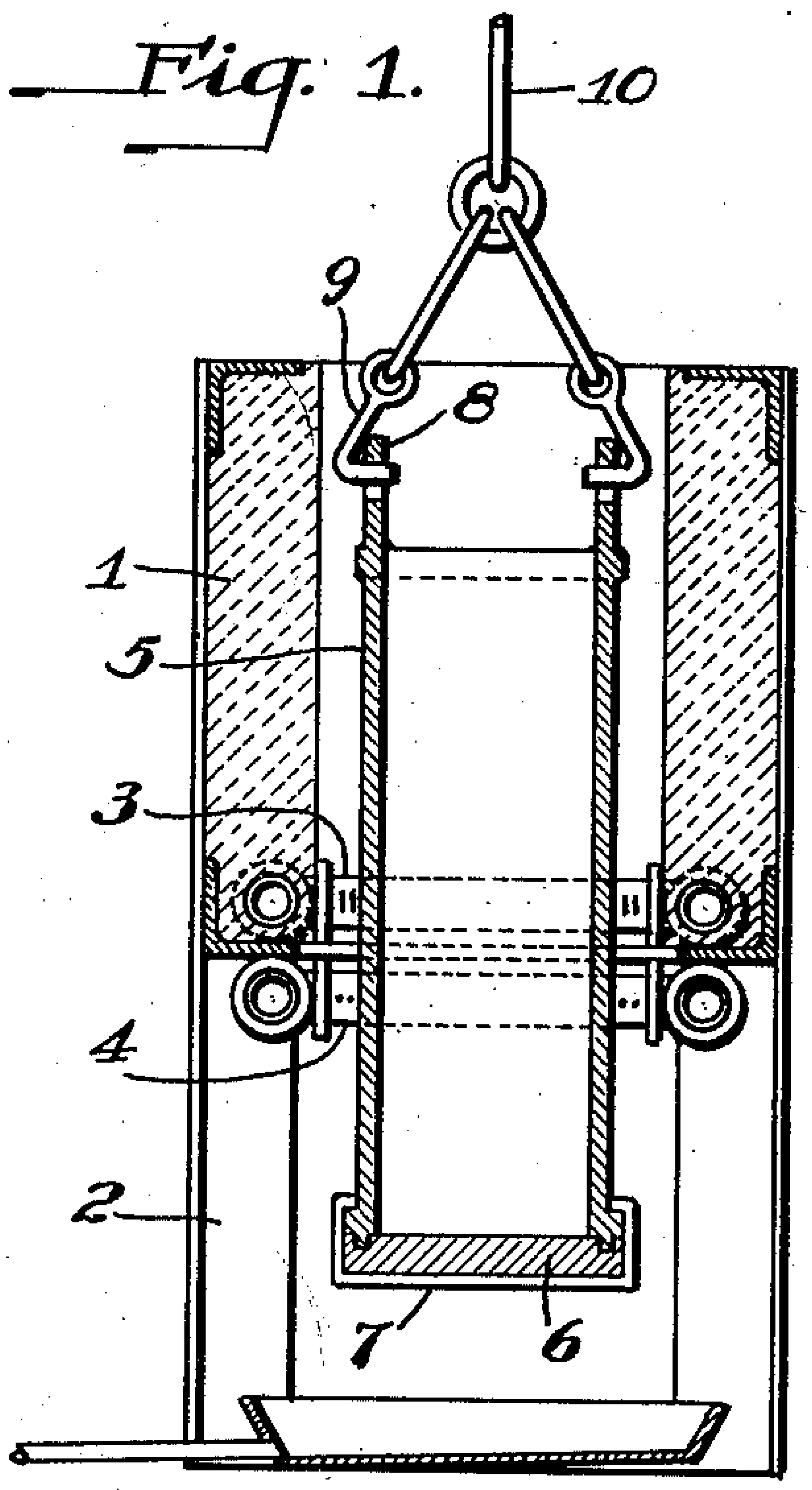


Fig. 2.

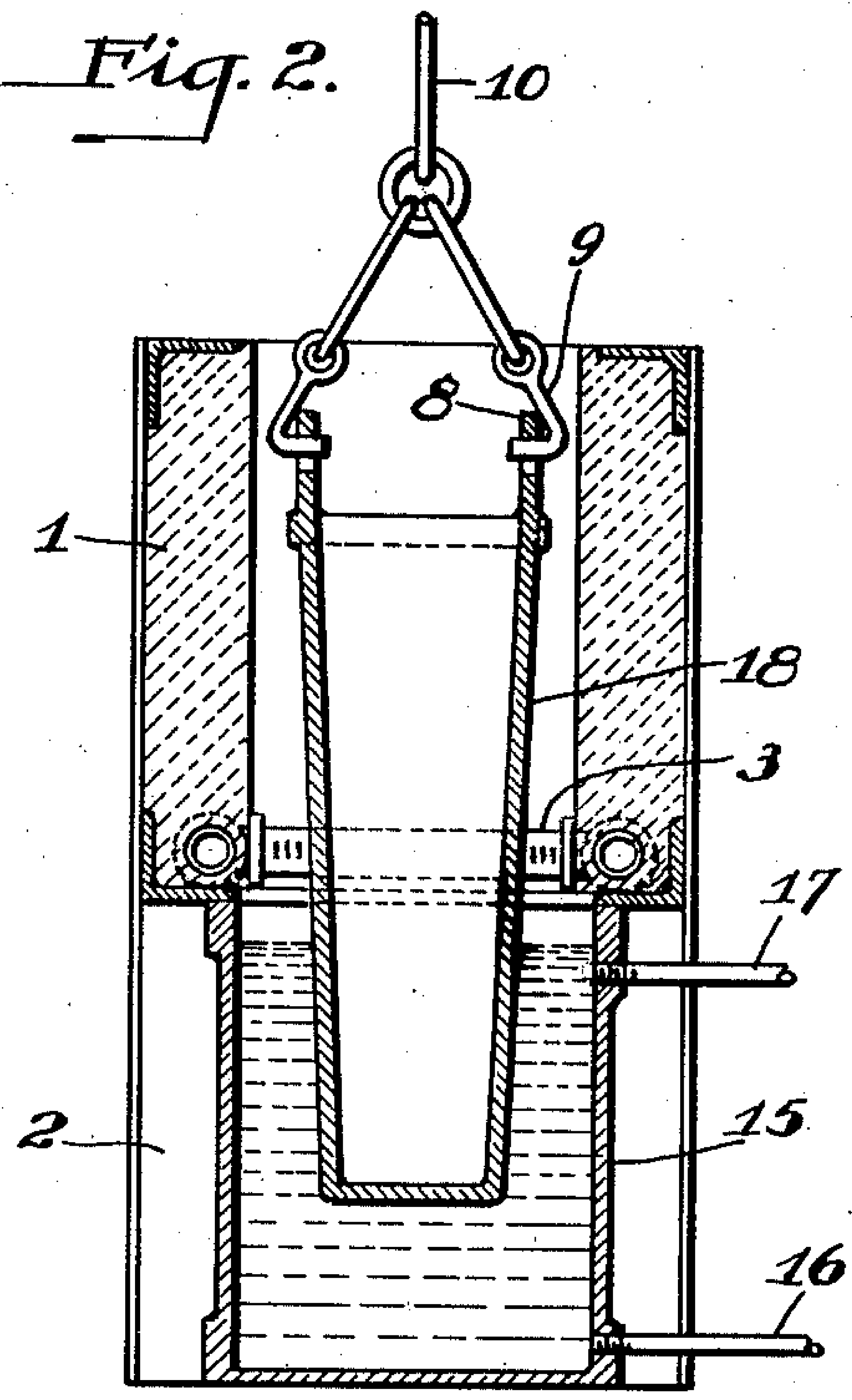
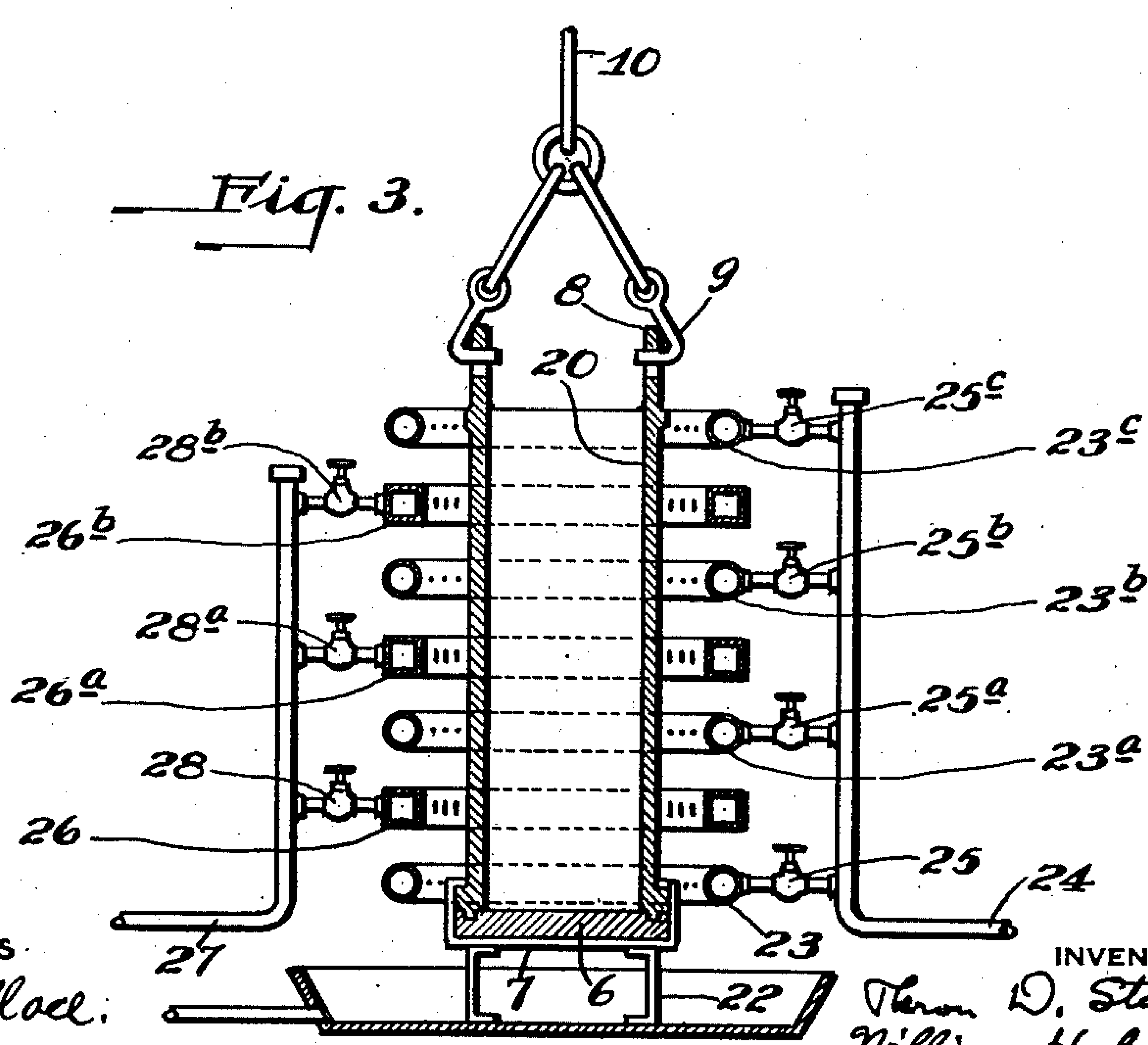


Fig. 3.



WITNESS

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Patented Oct. 7, 1930 **1,777,657**

UNITED STATES PATENT OFFICE

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METHOD OF FORMING INGOTS FOR WORKING

Application filed February 11, 1929. Serial No. 338,955.

The invention relates to the formation of ingots which are subsequently worked by rolling, forging, extrusion, and the like, and has particularly to do with the formation of ingots of aluminum base alloys, with reference to which it is herein described.

In the production of aluminum base alloy ingots for working, it is desirable to avoid piping at the tops which necessitates cropping and corresponding scrap loss, and to avoid segregation, liquation, and porosity which may arise from the variations in the solidification temperatures of eutectic and other constituents of non-homogeneous alloys or from other causes. On the other hand, it is desirable to produce such a grain structure throughout the ingots as will best meet the requirements of the particular manner of working to which they are to be subjected, and such a grain structure as will result in the best physical properties of the worked metal.

Prior to our invention, as far as is known to us, the best results in the production of aluminum base alloy ingots have been obtained 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 their bottoms and advancing the spray upwardly upon the molds or the molds downwardly through the spray. As compared to natural cooling of the ingots accompanied by heading the molds with additional metal as the ingots solidify and shrink, this progressive cooling materially reduces the piping, lessens the tendency to segregation and liquation, and eliminates a part of the gas-occlusion porosity, as well as that due to shrinkage. However, the grain structure of the ingots progressively cooled in the manner explained is unsatisfactory. It is unsuitable for some forms of metal working, and does not lend itself to the attainment of the best physical properties of the worked metal.

By cutting from end to end many full sized aluminum base alloy ingots thus progressively cooled, and polishing and etching the cut surface, we have found that they have rather coarse grain structures of irregular sizes, and elongate dendrite forms extending upwardly and inwardly from the outer faces to the centers of the ingots. In the commercial forging of such ingots corner and surface cracks frequently develop rendering the forged articles unsuitable for purposes where strength is required, for example for articles, such as airplane propellers, which in use are subjected to very rapid alternating stresses. Aside from this loss of strength due to such cracks, such worked metal possesses substantially less tensile strength than that produced according to our invention, and as will presently be explained by descriptions of comparative tests. Furthermore, due to the segregation, liquation and porosity characteristics of the ingots thus progressively cooled, metal at different parts of the ingots did not have uniform physical properties.

The object of our invention is to provide a method of forming, particularly of aluminum base alloys, ingots for working, the ingots having such grain structures, and such freedom from segregation, liquation, and porosity that the worked metal has high and uniform physical characteristics and does not develop surface 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 alloy metal in an ingot mold from its bottom to its top, while applying heat to the unsolidified portion of the metal above its progressively rising plane of solidification.

In the practice of our invention as applied to the formation of aluminum 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, 23^a, 23^b and 23^c, 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, 25^a, 25^b and 25^c. Between adjacent water spray pipes there are burners 26, 26^a and 26^b, each connected to a fuel supply pipe 27 from which flow of fuel is independently controlled by valves 28, 28^a and 28^b.

In the operation of the apparatus of Fig. 3, 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 23^a, 23^b and 23^c are not used, but where necessary the upper burners 26^a and 26^b 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 23^a is brought into play by opening valve 25^a, burner 26^a 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 the 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 solidified 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 22 inches from an aluminum base alloy containing from about 4 to 5% copper, about 0.75% manganese, and about 0.75% silicon, and by the use of the apparatus of Fig. 1, the best grain structures, coupled with freedom from prejudicial segregations, liquation and porosity characteristics, are produced by lowering the ingot mold at a rate of about $1\frac{5}{16}$ inches per minute while spraying on it twenty gallons of water per minute under a pressure of about 6 lbs. per square inch, and while maintaining the unsolidified metal at a temperature of from about 1200 to 1250° F., preferably at or near the lower part of its temperature range.

The advantage of this invention in the improved physical properties of metal worked from ingots having equiaxed grain structures produced in the manner explained in the foregoing example, and being substantially free from prejudicial segregation, liquation and porosity characteristics, is apparent from the tensile strength of the worked metal as compared to metal of the same composition worked from ingots having the coarser grain structures which characterize the formation of ingots according to prior practice. Test bars cut from an ingot formed of an aluminum base alloy of the above described composition, the metal having been reduced 37.7% by forging, showed an average tensile strength of 57,125 lbs. per square inch, and an average elongation of 7.4%, while test bars of metal of the same analysis cut from an ingot formed according to prior procedure and having a consequent coarser grain structure, the metal having been reduced 43.7% by forging, showed an average tensile strength of 47,813 lbs. and an average elongation of 3.9%. Although the metal of the coarser grained ingot had been given a greater reduction, and, other factors being the same, would accordingly have a higher tensile strength and elongation, nevertheless the metal of the fine equiaxed grain structure ingot produced according to this invention had a tensile strength nearly 10,000 lbs. greater than, and a percentage of elongation nearly double that, of the coarser grained ingot. This specific example of the advantage of this invention in worked aluminum base alloys is typical of a large number of similar test which we have made, and of which detailed descriptions would be merely a cumulative showing of the advantage of this invention.

Ingots formed according to this invention have the well known advantages incident to the elimination of pipes at their tops, and have also the advantages of being free from prejudicial segregation, liquation and porosity characteristics. These advantages are substantial, and important in the production of aluminum base alloy ingots for working. Another marked advantage of the invention resides in the grain structure of the ingots, which structure not only results in very substantially improved physical properties, but also eliminates the tendency of the ingots to develop corner and surface cracks when worked.

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 an aluminum base alloy an ingot for working having a readily workable 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 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 an aluminum base alloy 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 an aluminum base alloy 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.