

Nov. 21, 1967

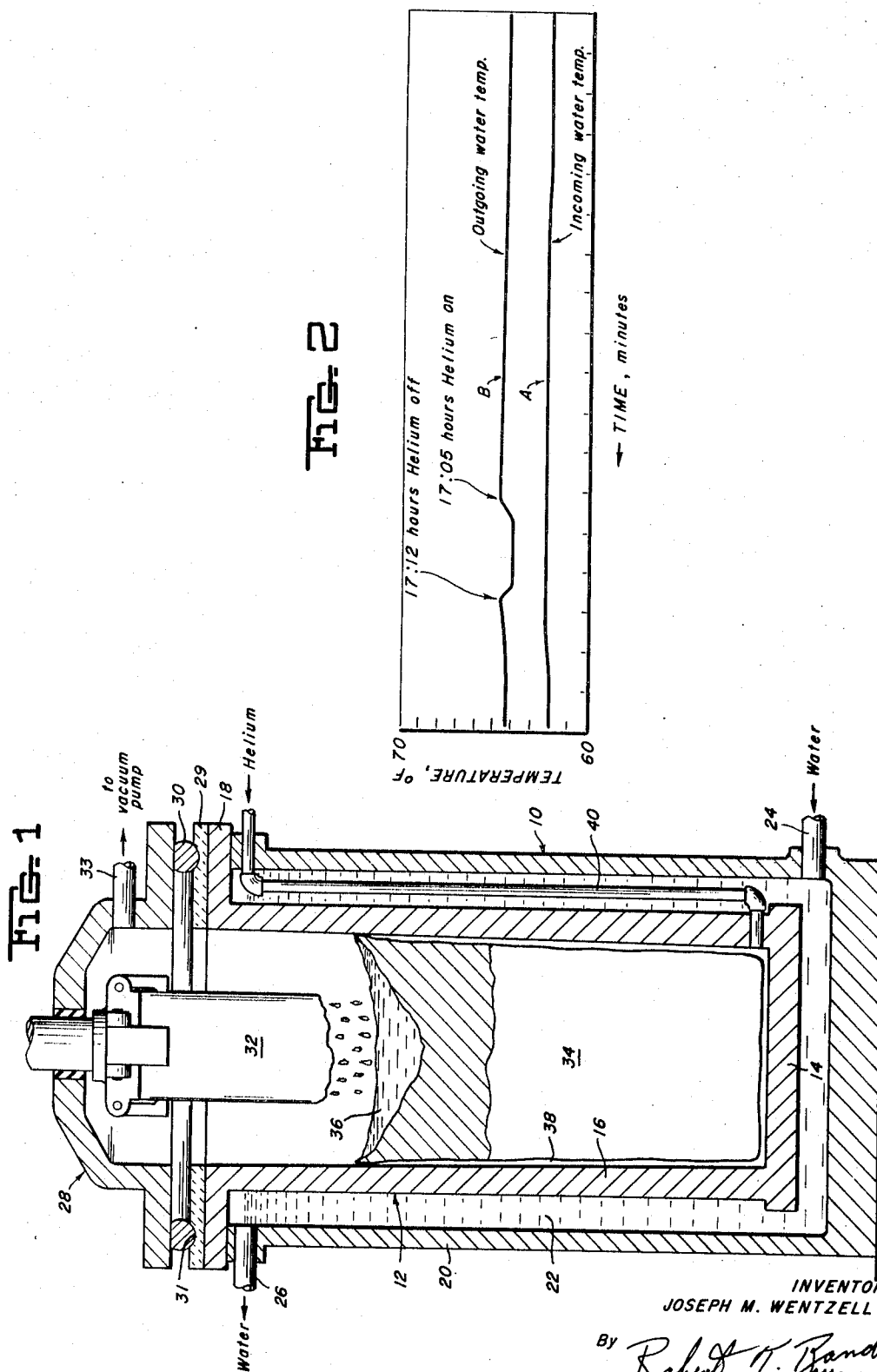
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METHOD FOR CONTROLLING THE COOLING OF CAST METAL.

Filed Dec. 13, 1965

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

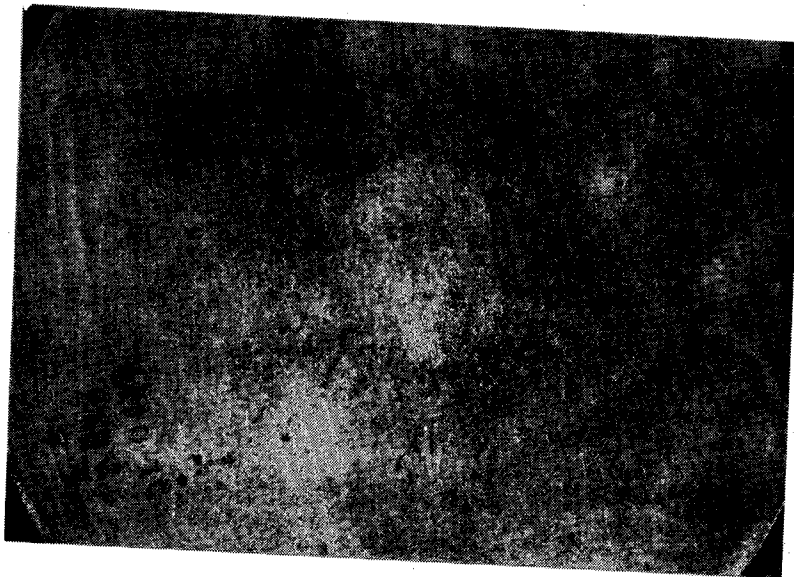


FIG. 3

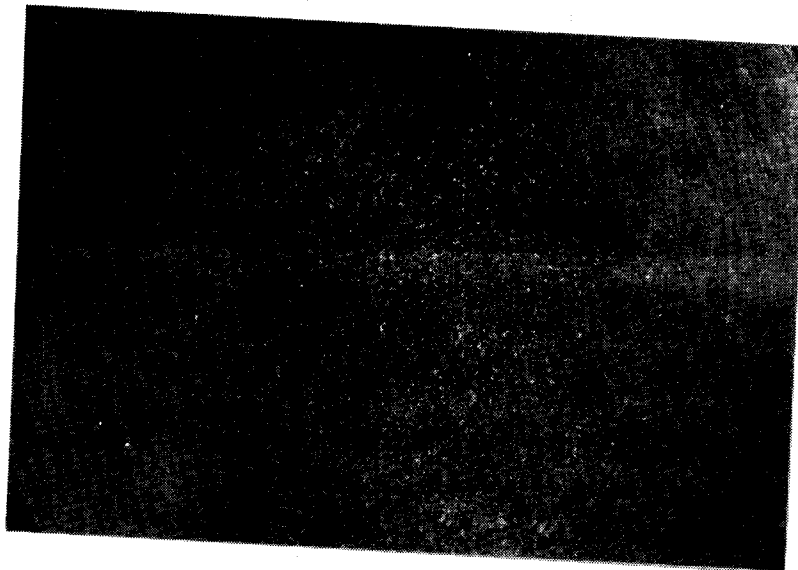


FIG. 4

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METHOD FOR CONTROLLING THE COOLING OF CAST METAL

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This invention relates to a method for controlling the cooling of an ingot, and is particularly concerned with the method for controlling the extraction of heat from an ingot during the casting thereof.

It is well recognized in the industry that the cooling rate of an ingot during the casting thereof is highly influential in producing a variety of characteristics in the cast metal. Perhaps the foremost effect which is influenced by the cooling rate is the phenomenon known as chemical segregation wherein one part of the ingot is enriched in one component at the expense of other portions of the ingot. Moreover, the cooling rate of an ingot during the casting thereof is directly related to the overall production rate and, where critically controlled, results in lower costs and permits the production of large ingots which are free from objectionable amounts of segregation. This is true, regardless of the melting technique employed in producing the cast ingot.

However, the problem with ingot cooling becomes acutely critical where the melting method employed is that known in the industry as consumable electrode electric arc melting. In this process, material of the desired final composition in the form of electrodes, are remelted under various states of atmospheric control in order to refine various aspects of the base metal composition. These aspects include the minimization of inclusions, degasification and control of grain structure, as well as the assurance of chemical homogeneity throughout the entire ingot.

Various approaches have been taken to control chemical segregation, including controlling the melt rates and utilizing liquid cooled molds. Most of these methods, however, have met with limited success because of the physical phenomenon involved. It is a well-known fact that most metals and alloys are characterized by the phenomenon of shrinking when undergoing a change from the liquid to the solid state. The shrinkage which occurs continues as the material cools, with the result that a gap forms between the mold wall and the ingot which is characterized by the absence of an atmosphere where there exists a progressive axial solidification from the bottom of the ingot upwardly. Essentially, the gap is a vacuum gap, since the space has been created by solidification shrinkage at all except the top most portion of the ingot which is characterized by the meniscus of the molten pool on top of the ingot. This molten metal appears to act as a liquid sealant as the ingot solidifies. The existence of the gap between the cooling ingot and the mold wall greatly decreases the rate of heat flow from the ingot to the mold wall, with the result that a deeper molten pool is formed. Since the rate of extraction of heat from the ingot is greatly reduced, a large volume of metal is subjected to the liquidus-solidus temperature range for a longer period of time, thereby fostering conditions which favor segregation and ingot heterogeneity. Since segregation occurs during the stage when the melt consists of two or more phases, i.e., liquid and solid, it has been concluded that segregation is aided by expanding the time any one portion of the melt remains in the transition phases. It is believed that these may be effective in consumable electrode electric arc melted materials for producing that type of segregation known in the trade as "freckles."

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In order to alleviate these conditions, the present invention provides for introducing into the aforementioned gap a material having a high coefficient of thermal conductivity which will effectively couple the ingot to the mold wall to provide conduction and convection as well as radiation heat transfer for the proper control of the heat flow from the ingot to the mold wall to thereby minimize segregation.

An object of the present invention is to provide an improved method of casting which minimizes segregation.

Another object of the present invention is to provide a method whereby relatively large ingots can be produced which are characterized by freedom from objectionable amounts of segregation.

A more specific object of the present invention is to provide a method for coupling a solidifying and cooling ingot to a mold wall to provide for the controlled extraction of heat from the ingot through the mold wall.

Other objects of this invention will become apparent when read in conjunction with the following description and the drawings in which:

FIGURE 1 is a fragmentary view of an apparatus for the consumable electrode melting of metals in which the method of the present invention may be utilized;

FIGURE 2 is a portion of a temperature chart which illustrates the relationship of the incoming and outgoing water temperatures at any given instant during the melting of a heat;

FIGURE 3 is a macrograph of a billet which has been produced from an ingot employing prior art consumable electrode melting process; and

FIGURE 4 is a macrograph of an ingot which was melted in a consumable electrode furnace employing the method of the present invention.

Referring now to the drawings, and to FIG. 1 in particular, there is illustrated a consumable electrode electric arc furnace, shown generally at 10, which comprises, inter alia, a crucible 12 formed of a base 14, upwardly extending mold walls 16 which terminate in a flange 18 for mounting to the superstructure of the furnace 10, and an outside wall or jacket 20 disposed in spaced relation to surround the mold wall 16. The base 14, mold walls 16 and flange 18 are usually constructed as an integral unit and are formed of a material having a high coefficient of heat conductivity, for example copper or aluminum. A coolant 22 is disposed to flow within the space between the jacket 20 and the integral unit of the base 14, mold walls 16 and flange 18. Water has been effectively used as the coolant and is admitted at inlet 24 and discharged at outlet 26.

The crucible 12 is disposed to be secured to the superstructure 28 of the furnace by any suitable means (not shown) and is maintained electrically insulated by insulating ring 29 and in vacuum-tight relation thereto by means of O-ring 30 disposed in seating engagement within the V-groove 31 in the ring 29 and between the superstructure 28. The entire structure, that is superstructure 28 and crucible 12, is connected to suitable vacuum pumps (not shown) by means of conduit 33 for maintaining a predetermined vacuum within the crucible 12 and the associated structure of the furnace. A consumable electrode 32 is vertically suspended within the superstructure 28 by any suitable means (not shown), extends a predetermined distance downwardly into the crucible 12, and is progressively moved downwardly as the electrode 32 is melted to form the ingot 34. As the consumable electrode 32 melts to form ingot 34 and the metal of ingot 34 solidifies progressively axially from the bottom of the mold upwardly, a molten pool 36 in the general shape of a meniscus is maintained on top of the cooling ingot 34. The meniscus

shaped molten pool 36 extends to ingot wall 16 and has its greatest depth near the center of the ingot.

As illustrated in FIG. 1, as the ingot 34 solidifies and cools it shrinks from the mold wall 16, thus providing the gap 38 between the ingot 34 and the mold wall 16. Since the molten pool 36 extends in meniscus shape into contact with the mold wall 16, the gap 38 is characterized by the absence of atmosphere. In order to provide for a sufficient coupling between the ingot 34 and the mold wall 16, the crucible 12 is provided with conduit 40 which leads through the mold wall 16 near the base 14 in communication with the gap 38 and is connected to a source (not shown) of a non-reactive gas having a high coefficient of thermal conductivity. As melting progresses and the gap 38 is established, a gas, preferably a high thermal conductivity gas having a high coefficient of thermal conductivity, for example helium, is introduced into the conduit 40 and is conducted into the gap 38 in order to provide an effective coupling between the ingot 34 and the mold wall 16 to control the flow of heat therefrom. It has been found that if the pressure of the gas is measured at the entrance of the conduit into the crucible 12, a line pressure of between 10 and 80 mm. is sufficient to effectively couple the ingot to the mold wall. It is preferred to maintain the partial pressure of the non-reactive gas greater than that above the molten pool 28 so that a small amount of leakage of the non-reactive gas occurs, which leakage is thereafter swept from the chamber, for example by vacuum pumps (not shown). By providing a source of non-reactive gas characterized by a high coefficient of thermal conductivity within the gap 38 and maintaining the same at a slightly positive pressure, effective control of the heat from the ingot to the mold wall can be provided to thereby minimize segregation.

In practice, an ingot having the composition known in the trade as Inco 718 was formed into an electrode 32 for remelting by the consumable electrode vacuum arc remelting furnace procedure. The crucible 12 was assembled as generally illustrated in FIG. 1. The crucible 12 was provided with conduit 40 extending downwardly along the mold wall 16 and extended into the mold cavity through the wall 16 near the base plate 14. As assembled, the melting cavity was evacuated and melting commenced. As the ingot 34 solidified and shrank from the mold wall, helium was introduced through conduit 40 into the gap 38 at a rate of two cubic feet per hour (STP).

Reference is now directed to FIG. 2 which illustrates the effective coupling of the cooling ingot to the mold wall through the injection of helium into the gap 38. In FIG. 2 the trace A is representative of the temperature of the water coolant as it enters into the space 22 at inlet 24 of the crucible 12 and trace B represents the temperature of the coolant as it emerges from exit 26 of the crucible 12. As clearly demonstrated in FIG. 2, at 17:05 hours the flow of helium supplied to the gap 38 through conduit 40 was interrupted with the result that a decrease in the exit water temperature was noted. The helium supply was interrupted for a total of 7 minutes. Thereafter, at 17:12 hours the flow of helium was continued and the temperature of the water at the exit port rose, thereby demonstrating the effective coupling of the ingot to the mold wall.

As stated hereinbefore, the process of the present invention is effective for minimizing segregation which occurs during the casting of metals and the cooling thereof into ingot form. Reference is directed to FIG. 3 which is a photomicrograph of a cast composition employing the process of the prior art. Following the casting of the material into a 20-inch diameter ingot, the cooled ingot was forged into an 8-inch diameter billet which was thereafter sectioned to produce the photomicrograph illustrated in FIG. 3. The structure illustrated in FIG. 3 clearly demonstrates the segregation which has occurred, and this segregation has persisted even through forging from a 20-inch

diameter ingot to an 8-inch diameter billet. On the other hand, referring to FIG. 4 there is illustrated a photomicrograph of the same composition which was cast employing the process of the present invention. This material was cast as a 20-inch diameter ingot and the photomicrograph of FIG. 4 is that of the as-cast structure. It is clear from FIG. 4 that very little segregation has occurred in this ingot which has employed the process of the present invention. The as-cast structure has been selected for FIG. 4 since this is the condition at which the maximum amount of segregation would be expected to be revealed. The evidence of FIG. 4 clearly demonstrates that the process of the present invention is highly effective for reducing the occurrence of segregation and especially that known in the trade as "freckles."

Very little modification of existing standard mill equipment is required to practice the process of the present invention. Such modifications are inexpensive, and the method of the present invention adds very little cost, if any to the overall production of metal, especially that produced utilizing the consumable electrode vacuum remelting process. It is, of course, understood that the process of the present invention is also effectively used where conventional teeming techniques are utilized, for example in the production of big-end-up and big-end-down ingots. By the introduction of a gas having a high coefficient of thermal conductivity into the shrinkage cavity existing between an ingot mold wall and the solidifying ingot, the cooling ingot is effectively coupled to the ingot mold wall for controlling the rate of heat transfer to the ingot mold wall and thus controlling the cooling rate of the ingot.

I claim:

1. In the process of casting molten metal in a consumable electrode melting furnace equipped with a water-cooled ingot mold, and a superstructure associated therewith including means to control the atmosphere in which such melting is performed, the ingot being characterized by solidifying progressively axially from the bottom of the ingot mold upwardly and in which the molten metal on top of the ingot forms a sealing contact with the mold wall, the improvement comprising injecting a gas characterized by a high coefficient of thermal conductivity adjacent the bottom of the ingot and into the space formed between the mold wall and the solidified portion of the ingot, said gas being under sufficient pressure to leak through the sealing contact formed by the molten metal on top of the ingot and the mold wall, and causing said gas to leak through the sealing molten metal contact while said control means maintains a controlled atmosphere over the said molten metal on top of the ingot.

2. The process of claim 1 in which the gas is injected during the casting operation.

3. The process of claim 1 in which the gas is helium.

4. The process of claim 3 in which the line pressure of the gas, before it is injected into the space between the mold wall and the solidified metal, is in excess of the pressure above the molten metal on top of the ingot.

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