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CASTING OF METALS AND ALLOYS

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The present invention relates to casting of metals, and more particularly to a special and novel method for effectuating grain refinement in metal castings and to generally improve the metallurgical characteristics thereof.

As is known to those skilled in the art, grain size can exert a pronounced influence anent the behavior of metal castings subjected to further processing, e.g., heat treatment, working, etc. Metal castings in general are inherently more amenable to heat treatment if they are of small grain size and generally manifest better mechanical properties than when characterized by coarse-grained structures. While the benefits of fine-grain castings are recognized, the approaches to achieving grain refinement have been many and have been the subject of considerable discussion. Proposals to effect grain refinement have included stirring and/or agitation of the melt during solidification; causing acceleration of cooling rate; using nucleating or inoculating agents; employing electromagnetic induction effects; and utilizing vibration principles. It is the latter type of application to which this invention is directed.

It is known to modify and refine the structure of cast metals and alloys by vibrating the complete body of molten metal to be cast throughout the whole period of solidification. This refinement is associated with a decrease in the grain size, which is often desirable since it can facilitate, for example, subsequent hot- or cold-working. At the same time, such vibration techniques have led to a reduction in the heterogeneity of the metal or alloy or, in the case of cast iron, for example, to changes in the microstructure.

Vibration techniques have been applied in a variety of ways, the chief of which has been vibration of the mold and vibration of an immersed rod or probe. Rather elaborate apparatus has been proposed with respect to vibration of the mold. For example, it has been suggested that the mold be affixed by rigid coupling to a table which in turn could be oscillated. As can be appreciated, a substantial amount of energy would be required to rock or vibrate the table and mold. Further, it has been indicated that a significant amount of energy is lost upon shrinkage of the solidifying material from the mold wall. In the past, application of techniques employing an immersed rod has been severely restricted by the fact that refinement only occurred in a small region of the vicinity of the vibrating probe.

Although attempts were made to overcome the foregoing difficulties and other difficulties, none, as far as I am aware, was entirely successful when carried into practice commercially on an industrial scale.

It has now been discovered that grain refinement can be effected substantially throughout metal castings by a specially controlled process wherein vibration of a cast melt is applied only to the portion of the molten body of metal undergoing incipient solidification, that is to say solidification which occurs when the solid phase begins to form by nucleation but before there is sufficient solid present to render the material "pasty." Castings produced in accordance with the invention manifest a substantially uniform and refined-grain structure and are amenable to further treatment including heat treatments, working operations and the like.

It is an object of the present invention to provide metal castings of refined-grain structure.

Another object of the invention is to provide a method for effecting grain refinement of metal castings and to achieve uniformity of grain structure substantially throughout the castings.

The invention also contemplates providing a method for refining the grain size and for generally improving other metallurgical properties of metal castings.

Generally speaking, the present invention contemplates markedly improving the grain structure of metal castings by subjecting a molten body of the metal to be cast to vibration only in a region of the melt undergoing said incipient solidification. The reason is not fully understood, but it appears possible that vibration during this period greatly increases the number of points or nuclei from which solidification proceeds. When once this effect has been produced, vibration can be discontinued. Solidification then proceeds from each of the nuclei and, since their number has been increased, the grain size of the solid ingot or other casting is reduced.

In carrying the invention into practice, a metal or alloy is cast in a mold so that solidification takes place progressively from one end of the mold to the other and vibration is applied to each portion of the metal in turn while it is undergoing incipient solidification by a source of vibration that is moved relatively to the mold as solidification progresses. At any one time only a part, even a small part, of the total volume of metal that is in the course of solidification is subjected to vibration, and thus a localized source of vibration such as a vibrating probe can be used. Moreover, the amount of energy required is considerably less than if the whole of the solidifying metal was vibrated during the whole time it was solidifying. The process according to the invention is thus particularly useful in casting metals and alloys of low thermal conductivity and correspondingly long times of solidification, for example, nickel-chromium and nickel-chromium-cobalt based high temperature alloys.

The invention will be described in more detail in relation to the casting of ingots, to which it is particularly applicable, but it will be understood that it is also useful in the production of other castings.

Unidirectional solidification may be caused to occur by suitable adjustment of the dimensions of the ingot and of the thermal properties of the ingot mold. This may be done in a variety of ways. For example, the bottom of the mold may be made of cast iron or another substance with high thermal conductivity to act as a chill while the top is made of an insulating substance such as a refractory or of a substance that undergoes an exothermic reaction in contact with the metal.

The source of vibration is preferably a vibrating probe immersed in the molten metal. The probe is initially inserted into the region where solidification first takes place, i.e., that volume of molten metal undergoing incipient solidification, and during the solidification of the ingot the probe is moved relative to the mold so that the volume of metal in its incipient stage of solidification is always within the sphere of influence of the probe, and preferably so that the end of the probe is just ahead of and at a constant distance from the solidification front. Solidification generally begins at the bottom of the mold, and the probe is then progressively withdrawn from the solidifying ingot. The speed of withdrawal and the time at which it is commenced will depend upon the speed of solidification, and thus upon the dimensions of the ingot and the thermal characteristics of the ingot mold and of the solidifying metal.

The distance through which the vibrations from the probe are effective must also be taken into acount. The metal solidifies both along the mold from the end and inwards from the sides. However, it is generally impractical to move the probe relative to both the longitudinal- and the radial-solidification processes, so in order to insure that the refining effect extends over the whole cross-section of the ingot, the internal radius of the mold should be smaller than the distance within which vibrations from the probe are effective. To produce ingots of large diameter a multiplicity of probes or a single probe of large diameter can be employed.

In accordance with the invention, the progress of the solidification can be advantageously and is preferably followed by observation of the rate of cooling of the metal by employing a probe in conjunction with means responsive to variation in temperature, e.g., a thermocouple. To do this, the effective range of the probe is first determined, and the temperature responsive means, e.g., a thermocouple, is then preferably attached to the bottom of the probe so that the distance between the bottom of the probe and the thermocouple junction is equal to or less than the effective range of influence of the vibrations.

The probe, with a thermocouple preferably attached, can be inserted into the empty ingot mold so that the thermocouple is near the bottom, and liquid metal is then poured into the ingot mold. The onset of solidification in the vicinity of the thermocouple is indicated by a decrease in the rate of cooling. As soon as this is observed, retraction of the probe is commenced. The thermocouple is then moved into an adjacent zone or region where solidification has not commenced, and accordingly there is an increase in the cooling rate in the vicinity of the thermocouple. Once more, as solidification commences in the new position of the thermocouple, the cooling rate will be arrested and a further retraction can be made. Probe and thermocouple can be continuously retracted so as to keep the thermocouple moving with a predetermined thermal contour. Again, if desired, the signals from the thermocouple can be employed through a servo-mechanism to regulate the rate of retraction of the probe so that the thermocouple is always at the solidification front.

Whatever means are used to regulate the rate of withdrawal of the probe, the effect of the treatment will be that each part of the metal in the mold in turn is subjected to vibration while it is in a state of incipient solidification. This will increase the number of nuclei which are formed throughout the ingot and, as has already been explained, will effect grain refinement even though the major portion of solidification in each part of the ingot will occur beyond the effective range of the probe.

For the purpose of giving those skilled in the art a better understanding of the invention and/or a better appreciation of the invention, the following illustrative examples are given:

Example I

In the first test, a high temperature refractory alloy was cast into an ingot approximately 4 inches in diameter and about 6 inches long. The ingot mold employed was of graphite and was surmounted by a 4 inch exothermic feeder to stimulate the desirable directional solidification from bottom to top. A probe in the form of a steel rod ¾ inch in diameter was placed centrally inside the ingot mold and extended practically to the bottom. It was vibrated electromagnetically at a frequency of 100 c.p.s. with an amplitude of approximately 0.050 inch. A nickel-chromium-cobalt base alloy containing about 62% nickel, about 20% chromium, about 16% cobalt, about 2.5% titanium, about 1.6% aluminum, about 0.1% carbon, etc., of the type generally used for wrought gas-turbine blades and other similar applications, was prepared in the molten state and poured into the ingot mold. Pouring was complete in approximately 10 seconds. During the pouring operation the probe was continuously withdrawn

from the ingot so that the depth of immersion remained constant at approximately 1½ inches. As a result of this, a marked grain refinement was achieved. The columnar crystallites in the resulting ingot which, in the absence of vibration, would normally extend from the surface to the center, now occupied only a thin surface zone, the major portion of the center of the ingot exhibiting fine equiaxed crystallites of a desirable type.

Example II

In another test, the conditions were similar as in Example I except that the ingot produced was 8 inches in diameter and 10 inches long. In this case the ingot mold was filled in a period of about 20 seconds and the probe continuously retracted during the pouring procedure so that it remained approximately 2 inches below the surface of the liquid metal. The structure of the ingot produced showed grain refinement similar to that described in Example I.

Example III

In yet another test, an ingot 8 inches in diameter and 10 inches long was bottom poured, that is to say, the metal was conducted into the ingot mold through a hole in its base. Under these circumstances, solidification does not commence until pouring has ceased. As previously, the vibrating probe was inserted in the ingot mold before the latter was filled with metal. However, in this experiment it was found necessary to leave the probe in position with its end 2 inches from the bottom of the ingot mold for a period of between 30 seconds and 1 minute before commencing retraction thereof. The best results were obtained when the process of retraction occupied a period of about 30 seconds. By this technique, pronounced grain refinement was attained similar to that achieved in Example I. The following are further examples of alloys to which the invention may be applied:

No. 1	Co	Cr	Ti	Al	Mo	Ni	Percent
Range	15–25	10–20	1–3	3–7	4–7	substantially bal.	
Preferably	18–22	12–16	1–2	4–6	4.5–5.5	Do.	
e.g	20	15	2	4	5	Do.	
or	20	15	1.7	4.8	5	Do.	

No. 2	Co	Cr	Ti	Al	Ni	Percent
Range	12–24	15–25	1–4	0–4	substantially bal.	
Preferably	15–21	18–21	1.8–3.0	0.8–2.0	Do.	
e.g	16	20	2.5	1.6	Do.	

No. 3	Co	Cr	Ti	Al	Mo	W	Ni	Percent
Range	8–18	10–20	0–10	0–10	0–8	0–16	substantially bal.	
Preferred range	10–14	11–16	3–6	3–6	0–4	0–8	Do.	
e.g	12	15	4	4	1	5.5	Do.	
or	10	12	4	4	----	8	Do.	

No. 4	Co	Cr	Ti	Al	Ni	Percent
Range	0–10	12–24	0–5	0–5	substantially bal.	
Preferred range	0–2	17–21	0–3	0–2	Do.	
e.g	Nil	18	0.5	Nil	Do.	

In contrast to the above tests in which a substanttially constant relation was maintained between the position of the vibrating probe and the initial-solidification-front, which is that region where incipient solidification takes place, and grain refinement was produced throughout the whole ingot, in comparative tests with the same alloys in which the vibrating probe was immersed only in the top of the solidifying ingot and was maintained in the same position throughout the cooling, grain refinement was generally only observed within a radius of about 3 inches around the vibrating probe.

The probe is preferably made of a material which does not readily dissolve in the liquid metal. Alternatively, it may be of the same composition as the liquid metal when partial dissolution is not deleterious to the final product. The probe may be of any convenient shape or size, e.g., a cylindrical rod, a hollow cylinder or a multiplicity or rods or cylinders. It can be vibrated electromagnetically, pneumatically, hydraulically or by any other suitable method. The frequency of vibration is preferably between 10 and 1000 c.p.s., although other frequencies can be used to advantage. Increasing frequency and decreasing amplitude of vibration generally tend to reduce the sphere of influence of the probe, making it necessary to reduce the distance between the probe and the initial-solidification-front.

After the probe has been retracted from the ingot proper, it may, if desired, be retained in the feeder head of the solidifying ingot so that vibration of the top of the ingot may continue throughout the process of solidification. This, however, is not essential.

It will be appreciated that the precise details of the process according to the invention will vary, and will tend to be different for each specific application. Nevertheless, when once the conditions have been established in any given case, pronounced grain refinement can be obtained in accordance with the invention even in ingots of very large size, e.g., several tons in weight.

The present invention is particularly applicable to effecting grain refinement in hard refractory metal and/or alloy castings although it can be employed in casting metals in general.

It is to be noted that the present invention is not to be confused with casting methods wherein the whole of the molten metal is simultaneously subjected to vibration. As referred to hereinbefore, a substantial amount of energy is required in such different methods. In accordance with this invention, such difficulties are obviated.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and appended claims.

I claim:

1. A new and improved method for producing grain refined hard refractory metal castings possessing substantially equiaxed crystal structures throughout which comprises, pouring a body of molten metal into a mold, maintaining in the molten body of metal an assembly comprised of a probe and thermocouple attached to the bottom of said probe, initiating incipient solidification in the molten metal, subjecting only the volume of metal undergoing incipient solidification to vibratory action induced in the probe, the vibration being initiated at the onset of incipient solidification and before the molten alloy adjacent the mold walls freezes, maintaining the distance of effective vibrational energy such that it is at least equal to the distance between the bottom of the probe and the junction of the thermocouple and is at a substantially constant distance from the initial-solidification-front, and continuously withdrawing said probe from each successive volume of molten metal undergoing incipient solidification into an adjacent volume of molten metal undergoing incipient solidification upon a decrease in cooling rate of the preceding volume of metal as reflected by the thermocouple until solidification is substantially complete.

2. A new and improved method for effecting grain refinement in metal castings and for producing castings characterized by equiaxed crystals substantially throughout the cast structures which comprises, pouring a molten body of metal into a mold, subjecting only the volume of metal undergoing incipient solidification to vibratory action induced in a probe in the body of molten metal, the vibration being initiated at the onset of incipient solidification and before the molten alloy adjacent the mold walls freezes, maintaining the distance of effective vibrational energy at a substantially constant distance from the initial-solidification-front while continually retracting said probe from each successive volume of metal undergoing incipient solidification into another volume of metal undergoing incipient solidification until solidification is complete.

3. A new method for achieving improved grain structures in castings of nickel-chromium based high temperature alloys of low thermal conductivity whereby the castings so produced are characterized by substantially equiaxed crystal structures throughout which comprises, pouring into a mold a body of molten nickel-chromium base alloy, maintaining in the molten body of alloy a probe and means responsive to variation in temperature, subjecting only the region of molten alloy undergoing incipient solidification to vibratory action by causing continuous vibration of the probe at a frequency of about 10 to about 1000 cycles per second but without causing vigorous stirring of the molten alloy, the vibration being initiated at the onset of incipient solidification and before the molten alloy adjacent the mold walls freezes, and maintaining the distance of effective vibrational energy at a substantially constant distance from the initial-solidification-front while continuously retracting said probe from each successive region of molten alloy undergoing incipient solidification upon a decrease in cooling rate of the preceding volume of molten alloy as reflected by the means responsive to temperature variation into another region undergoing incipient solidification until solidification is substantially complete.

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