

[54] CONTINUOUS PROCESS FOR FORMING AN ALLOY CONTAINING NON-DENDRITIC PRIMARY SOLIDS

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164/281

[51] Int. Cl. B22d 27/08

[58] Field of Search 164/71, 77, 122, 123, 133,
164/82, 281; 266/34 A, 38; 23/295, 301 SP

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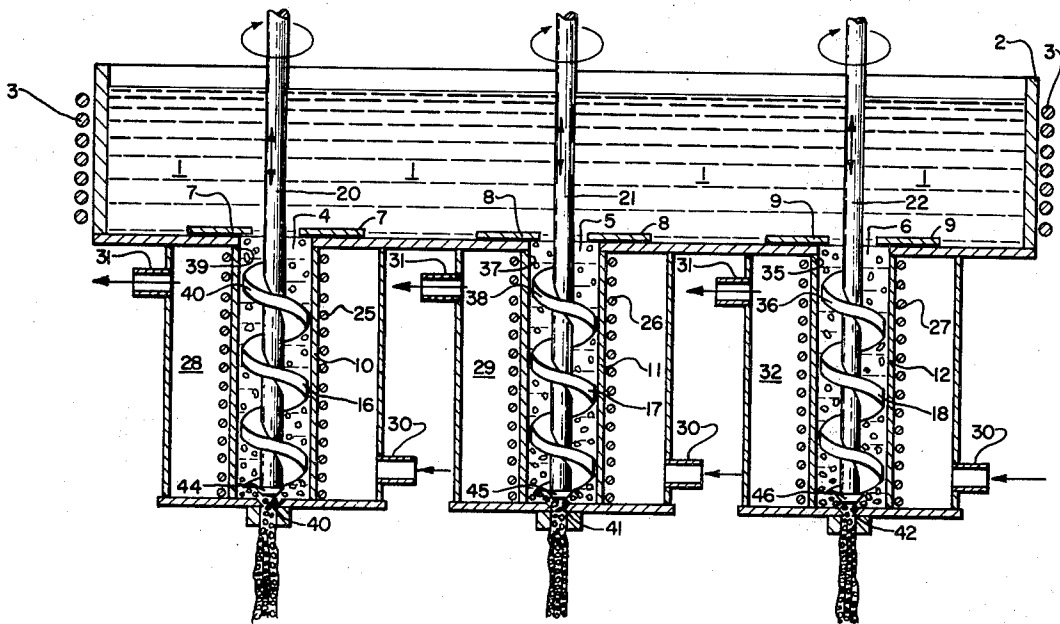
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[57] ABSTRACT

A process is provided for continuously forming a homogeneous mixture of a liquid-solid metal composition, wherein said solid comprises discrete degenerate dendrites or nodules, from a first metal composition which, when frozen from its liquid state without agitation forms a dendritic structure. The first metal composition is maintained molten in a first zone and then is passed into at least one agitation zone connected to said first zone. The first zone and agitation zone are sealed to prevent entrainment of gas into said agitation zone. In the agitation zone, the metal is vigorously agitated and cooled to solidify a portion thereof and to form primary solids comprising discrete degenerate dendrites or nodules while preventing the formation of interconnected dendritic networks. The primary solids comprise up to about 65 weight percent of the liquid-solid metal composition. The liquid-solid metal composition is removed from the agitation zone at about the same rate that the melted first metal composition is passed into said agitation zone. The metal removed from the agitation zone then can be cast.

21 Claims, 9 Drawing Figures



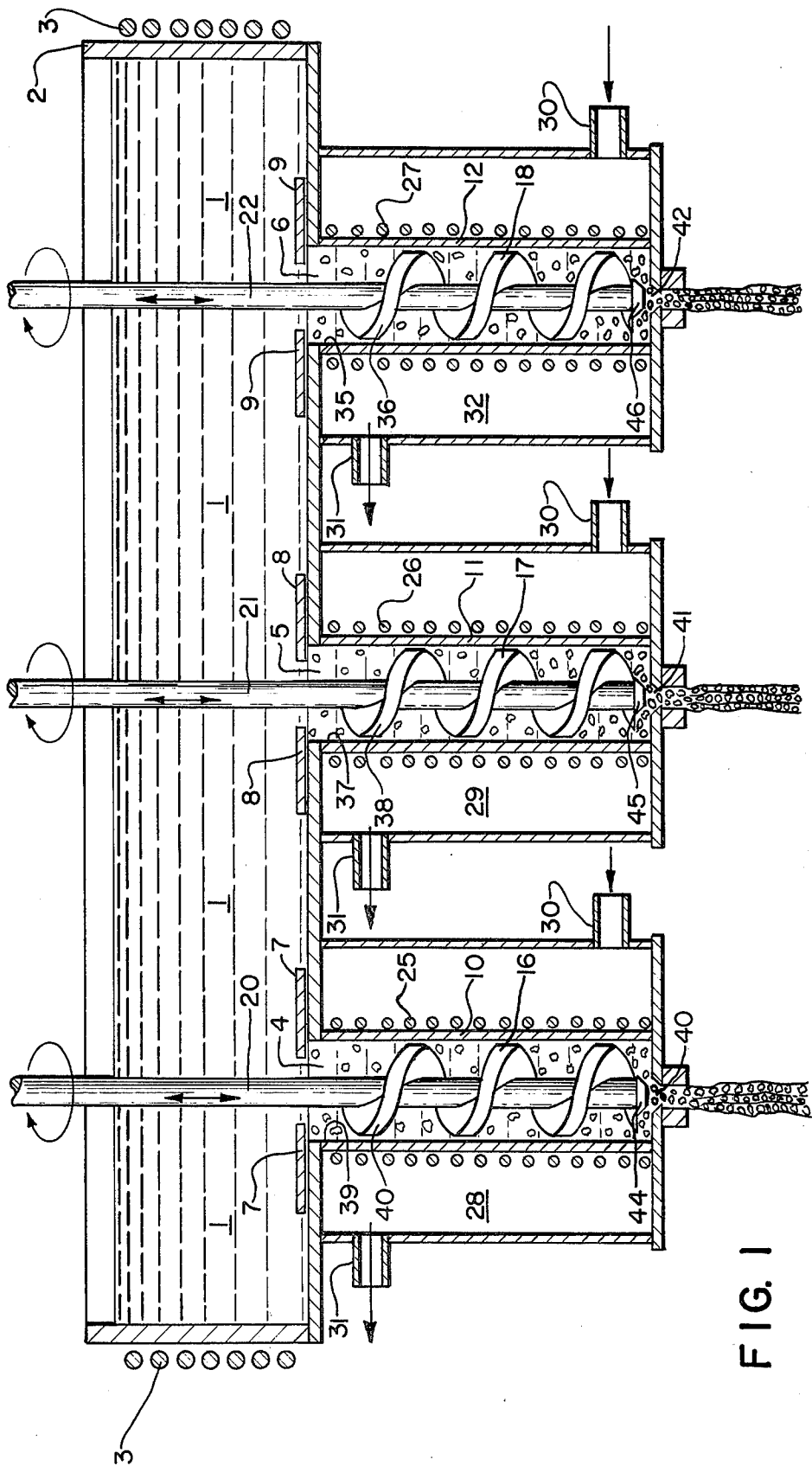


FIG. 1

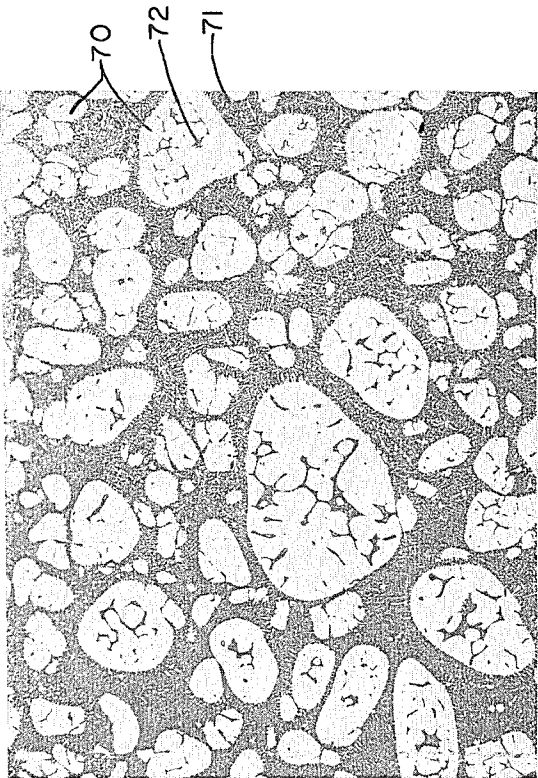


FIG. 4



FIG. 6

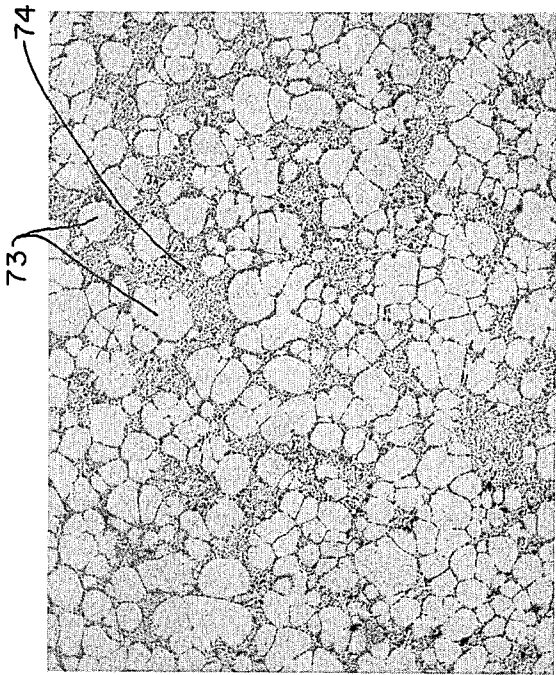


FIG. 5

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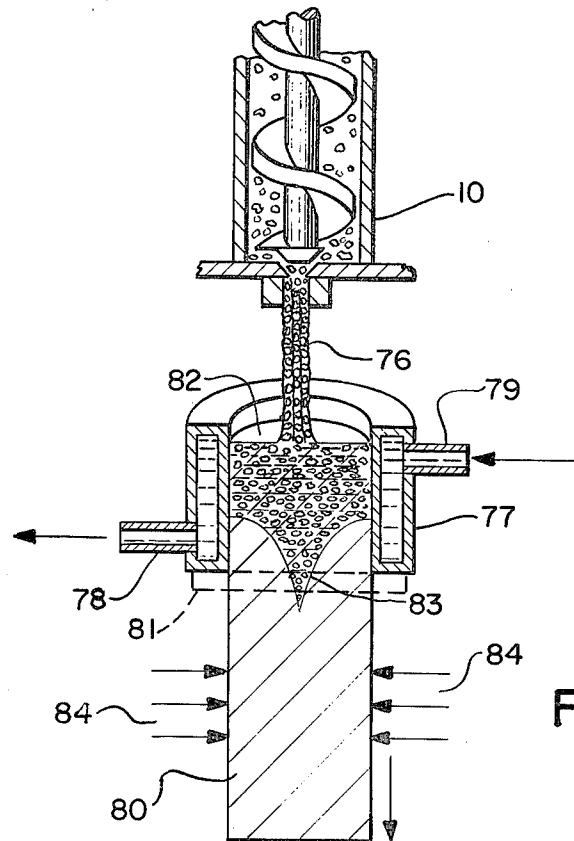


FIG. 7

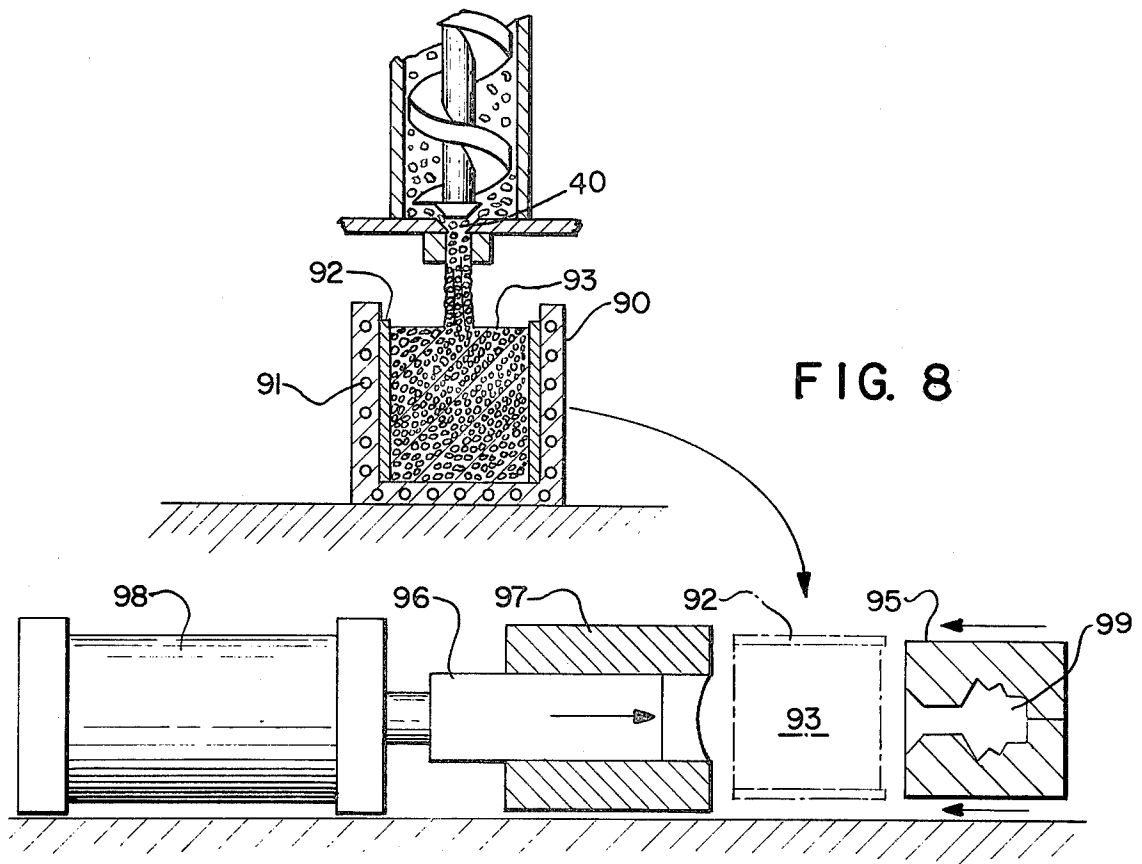


FIG. 8

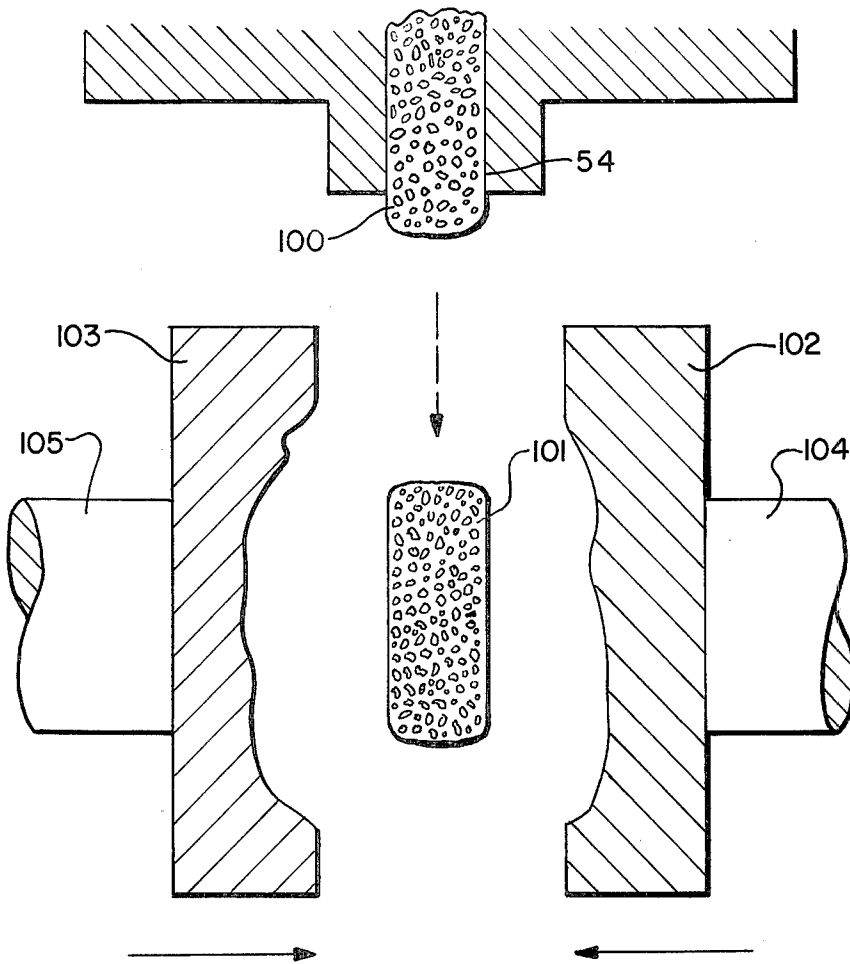


FIG. 9

CONTINUOUS PROCESS FOR FORMING AN ALLOY CONTAINING NON-DENDRITIC PRIMARY SOLIDS

The invention herein described was made in the course of work performed under a contract with the Department of the Army.

The present invention relates to a continuous process for making a solid or a liquid-solid metal composition containing non-dendritic primary solids and to the processes for shaping such compositions.

Prior to the present invention, alloys have been prepared containing non-dendritic primary solids by a batch method as disclosed in copending application Ser. No. 379,991, filed July 17, 1973 in the names of Robert Mehrabian, Merton C. Flemings, and David B. Spencer. As disclosed in that application, a metal alloy composition is formed by heating an alloy to a temperature at which most or all of it is in the liquid state and vigorously agitating the alloy, usually while cooling the alloy, to convert any solid particles therein to degenerate dendrites or nodules having a generally spheroidal shape. The degree of agitation must be sufficient to prevent the formation of interconnected dendritic networks and to substantially eliminate or reduce dendritic branches already formed within the alloy due to cooling. After the primary solids have been formed, the liquid remaining in the alloy composition can be allowed to cool to form a dendritic solid surrounding the primary solids.

It has been found that the compositions formed by the process of the invention described in the copending application provide substantial advantages in casting methods as compared to the prior existing casting methods in which a molten metal is poured or forced into a mold. A number of problems exist when casting molten alloy including the fact that when the liquid changes to the solid state, metal shrinkage normally is encountered and the cooling process is fairly long. Furthermore, a large number of liquid alloys are highly erosive to dies and molds and the high temperature of the liquids and their erosive characteristics make difficult or impossible the casting of such alloys as copper or iron alloys. By casting a liquid-solid slurry containing the non-dendritic primary solids, the severity of these problems is substantially reduced or eliminated since the casting is contacted with a metal composition having a relatively low temperature thereby reducing the erosive problem, cooling times and metal shrinkage.

The processes specifically described in the above-identified application produce products which have substantial advantages over the prior art. However, the processes specifically disclosed in that application are batch-type processes and have some disadvantages as compared to the continuous process disclosed specifically herein. In these batch processes, the entire liquid-solid composition is subjected to vigorous agitation including a top surface of the composition which is in direct contact with a gaseous surrounding atmosphere. Due to the vigorous agitation, there is some gas entrainment into the composition being formed which is undesirable since the entrapped gas may adversely affect articles which are formed therefrom. In addition, the batch technique generally is slow and temperature control generally is more difficult.

SUMMARY OF THE INVENTION

The present invention provides a process for forming

a metal composition containing degenerate dendritic primary solid particles homogeneously suspended in a secondary phase having a lower melting point than the primary solids and having a different metal composition than the primary solids wherein both the secondary phase and the solid particles are derived from the same alloy. The present invention is based upon the discovery that these compositions can be formed continuously or semi-continuously by vigorously agitating a solid-liquid mixture, which mixture is separated from any gaseous atmosphere by an alloy, in the molten state from which the liquid-solid mixture is derived. It has been discovered that by operating in this manner, the molten alloy can be directed continuously to an agitation zone which is maintained at a temperature at which the alloy becomes partially solid without entrainment of gas and in a manner such that control of the portion solid in the agitation zone can be maintained easily. The liquid-primary solid mixture then is passed from the agitation zone at about the same rate as the liquid entering the agitation zone which can be continuous or semicontinuous. The mixture can be cast or passed through a forming zone adjacent the agitation zone. The resultant composition can exit from the forming zone either as 100 percent solid or as a liquid-solid mixture. In either case, the composition comprises non-dendritic primary solids homogeneously dispersed in a second phase, which second phase can either be solid or liquid. When the secondary phase is liquid, the compositions so-formed can be allowed to cool or can be formed such as by casting. When the final product is entirely solid, it can be formed at a later time merely by heating it back to the liquid-solid temperature range wherein it may be thixotropic and rendered formable when subjected to shear forces.

DESCRIPTION OF SPECIFIC EMBODIMENTS

By the term "primary solid" as used herein is meant the phase or phases solidified to form discrete degenerate dendrite particles as the temperature of the melt is reduced below the liquidus temperature of the alloy into the liquid-solid temperature range prior to casting the liquid-solid slurry formed. By the term "secondary solid" as used herein is meant the phase or phases that solidify from the liquid existing in the slurry at a lower temperature than that at which the primary solid particles are formed after agitation ceases. The primary solids obtained in the compositions prepared by the process of this invention differ from normal dendrite structures in that they comprise discrete particles suspended in the remaining liquid matrix. Normally solidified alloys, in absence of agitation, have branched dendrites separated from each other in the early stages of solidification i.e. up to 15 to 20 wt. percent solid, and develop into an interconnected network as the temperature is reduced and the weight fraction solid increases. The structure of the compositions prepared by the process of this invention on the other hand prevents formation of the interconnected network by maintaining the discrete primary particles separated from each other by the liquid matrix even up to solid fractions of 60 to 65 wt. percent. The primary solids are degenerate dendrites in that they are characterized by having smoother surfaces and less branched structures which approaches a spherical configuration than normal dendrites and may have a quasi-dendritic structure on their surfaces but not to such an extent that interconnection

of the particles is effected to form a network dendritic structure. The primary particles may or may not contain liquid entrapped within the particles during particle solidification depending upon severity of agitation and the period of time the particles are retained in the liquid-solid range. However, the weight fraction of entrapped liquid is less than that existing in a normally solidified alloy at the same temperature employed in present processes to obtain the same weight fraction solid.

The secondary solid which is formed during solidification from the liquid matrix subsequent to forming the primary solid contains one or more phases of the type which would be obtained during solidification of a liquid alloy of identical composition by presently employed casting processes not employing vigorous agitation. That is, the secondary solid can comprise dendrites, single or multiphase compounds, solid solutions, or mixtures of dendrites, compounds and/or solid solutions.

The size of the primary particles depends upon the alloy or metal compositions employed, the temperature of the solid-liquid mixture and the degree of agitation employed with larger particles being formed at lower temperature and when using less severe agitation. Thus, the size of the primary particles can range from about 1 to about 10,000 microns. It is preferred that the composition contain between about 10 and 55 wt. percent primary particles since they have a viscosity which promotes ease of casting or forming without causing heat damage to the forming or casting apparatus.

As employed herein, the terms "agitation" or "vigorous agitation" as applied to the process of this invention mean that the liquid-solid composition is subjected to an agitation force sufficient to prevent the formation of interconnected dendritic networks and to substantially eliminate or reduce dendritic branches already formed on the primary solid particles.

In accordance with this invention, a metal alloy is rendered molten in a first zone which is in communication with an agitation zone. The agitation zone is connected to the first zone and is sealed to prevent entrainment of gas into the metal composition therein. The agitation zone is provided with means for cooling the metal composition therein and for vigorously agitating the metal composition therein. The degree of agitation in the agitation zone must be sufficient to prevent the formation of interconnected dendritic networks from the metal composition while it is cooled. The particular means employed for providing the degree of agitation is not critical so long as the interconnected dendritic networks are not formed and the primary solids are formed while the metal composition therein is cooled. The primary solids content of the metal composition in the agitation zone can comprise up to about 65 wt. percent of the liquid-solid metal composition. The liquid-solid metal composition is removed from the agitation zone through an outlet at about the same rate as the molten composition is passed into the agitation zone. The liquid-solid metal composition can be cooled to form a solid which can be subsequently reheated to a liquid-solid range for subsequent forming or casting at any time or the liquid-solid composition can be cast upon removal from the agitation zone. It is not critical to this invention that a particular mode of casting be employed. However, the continuous embodiment of

the process of this invention affords casting techniques not available in the prior art since the liquid-solid mixtures continuously produced herewith have a degree of structural strength which is not a characteristic of molten metal. This degree of structural strength affords the use of unique means for transporting and subsequently forming of the liquid-solid mixtures. The casting techniques afforded by this invention will be described below in greater detail.

Any metal alloy system or pure metal regardless of its chemical composition can be employed in the process of this invention. Even though pure metals and eutectics melt at a single temperature, they can be employed since they can exist in liquid-solid equilibrium at the melting point by controlling the net heat input or output to the melt so that, at the melting point, the pure metal or eutectic contains sufficient heat to fuse only a portion of the metal or eutectic liquid. This occurs since complete removal of heat of fusion in a slurry employed in the casting process of this invention cannot be obtained instantaneously due to the size of the casting normally used and the desired composition is obtained by equating the thermal energy supplied, for example by vigorous agitation and that removed by a cooler surrounding environment. Representative suitable alloys include magnesium alloys, zinc alloys, aluminum alloys, copper alloys, iron alloys, nickel alloys, cobalt alloys and lead alloys such as lead-tin alloys, zinc-aluminum alloys, zinc-copper alloys, magnesium-aluminum alloys, magnesium-aluminum-zinc alloys, magnesium-zinc alloys, aluminum-copper alloys, aluminum-silicon alloys, aluminum-copper-zinc-magnesium alloys, copper-tin bronzes, brass, aluminum bronzes, steels, cast irons, tool steels, stainless steels, superalloys such as nickel-iron alloys, nickel-iron-cobalt-chromium alloys, and cobalt-chromium alloys, or pure metals such as iron, copper or aluminum.

This invention will now be discussed upon reference to accompanying drawings, in which:

FIG. 1 is an elevational view of an apparatus having three agitation zones useful for effecting the process of this invention.

FIG. 2 is an elevational view of an apparatus having one agitation zone.

FIG. 3 is a cross-sectional view of the apparatus of FIG. 3 taken along line 2-2.

FIG. 4 is a reproduction of a photomicrograph showing the structure of a copper-10 percent tin-2 percent zinc casting made employing the teaching of this invention.

FIG. 5 is a reproduction of a photomicrograph showing the structure of a tin-15 percent lead casting made employing the teaching of this invention.

FIG. 6 is a reproduction of a photomicrograph showing the structure of a cast iron casting containing 2.48 percent carbon and 3.12 percent silicon.

FIG. 7 is an elevational view showing a means for continuously casting the liquid-solid composition obtained by the process of this invention.

FIG. 8 is a schematic view of a means for casting discrete portions of the liquid-solid composition obtained by the process of this invention.

FIG. 9 is a schematic view of an alternative means for casting discrete portions of the liquid-solid composition obtained by the process of this invention.

Referring to FIG. 1, a metal alloy in the liquid state 1 is retained within container 2. The metal alloy 1 can

be heated conveniently to the liquidus state or maintained at or above the liquidus temperature by means of induction heating coils 3 which surround container 2. Container 2 is provided with three openings 4, 5 and 6 the size of which are regulated by baffles 7, 8 and 9. Agitation zones 10, 11 and 12 are located adjacent each opening 4, 5 and 6 respectively and are joined to the bottom surface of container 2 in a manner to prevent gas from becoming admixed with the metal alloy within either container 2 or agitation zones 10, 11 and 12. Augers 16, 17 and 18 are provided within agitation zones 10, 11 and 12 respectively and are mounted to rotatable shafts 20, 21 and 22 which are powered by any suitable means (not shown). Each of the agitation zones 10, 11 and 12 is provided with induction heating coils 25, 26 and 27 and with a cooling jacket 28, 29 and 32 in order to control the amount of heat and the temperature of the metal alloy within the agitation zones 10, 11 and 12. Each cooling jacket is provided with a fluid inlet 30 and a fluid outlet 31. The distance between the inner surface 35 of agitation zone 12 and the outer surface 36 of auger 18 as well as the corresponding distances between surfaces 37 and 38 and surfaces 39 and 40 are maintained sufficiently small so that high shear forces can be applied to a liquid-solid mixture in the agitation zones 10, 11 and 12 sufficient to prevent the formation of interconnected dendritic networks while at the same time allowing passage of the liquid-solid mixture through the respective agitation zones 10, 11 and 12. Since the induced rate of shear in the liquid-solid mixture at a given rotational speed of the auger is a function of both the radius of the agitation zone and the radius of the auger, the clearance distance will vary with the size of the auger and agitation zone. To induce the necessary shear rates, increased clearances can be employed with larger augers and agitation zones. The bottom surface of agitation zones 10, 11 or 12 are each provided with an opening 40, 41 or 42 respectively so that the liquid-solid mixture in the agitation zones can be removed conveniently by gravity or, if desired by establishing a pressure differential between the upper surface of molten metal 1 and openings 40, 41 and 42. The effective opening 40, 41 or 42 can be controlled easily by raising or lowering the shaft 20, 21 or 22 so that the bottom end of the auger 44, 45 or 46 can fit into all or a portion of the respective openings 40, 41 or 42.

The operation of the apparatus shown in FIG. 1 will be described with respect to one auger shown therein. A metal alloy is introduced into container 2 wholly molten, partially solid or wholly solid. In any event, the metal alloy is rendered molten in container 2 by heat induction coils 3, if necessary. After the molten alloy is formed, the baffles 7 are opened to admit the molten alloy into agitation zone 10. The baffles 7 also minimize migration of primary solids from the agitation zone 10 into the container 2. Meanwhile, rotation of shaft 20 and auger 16 is initiated, for example at a rotational speed between about 100 and about 1000 r.p.m. The heat in agitation zone 10 is removed therefrom by heat exchange with a fluid, such as air or water, that enters jacket 28 through inlet 30 and exits through outlet 31. Heat induction coils 25 are provided for process control in the event the metal composition in agitation zone 10 is cooled to a fraction solid content above that desired, e.g. above about 65 weight percent. The molten metal 1 is passed continuously through the opening

4 into the agitation zone 10 wherein the desired quantity of heat content of the alloy is removed to render it partially solid and partially liquid wherein the solid portion comprises primary solids. The rate at which the liquid-solid mixture exits agitation zone 10 depends upon the effective opening in hole 40 controlled by the position of the end 44 of the auger 16. The heat exchange within agitation zone 10 can be controlled easily by controlling the flow rate and temperature of the cooling fluid in jacket 28, controlling the power input in induction coils 3, and the flow rate of metal through agitation zone 10 by controlling the size of the opening 4 baffles 7 and the size of the opening 40 with the end 44 of auger 16. Thermocouples (not shown) can be provided along the length of agitation zone 10 and at the end thereof in order to monitor the temperature of the liquid-solid mixture within agitation zone 10. By operating in this manner, the molten metal in zone 2 serves to seal the liquid-solid mixture within zone 10 from the outside gaseous atmosphere thereby preventing undesirable random entrainment of gas within the liquid-solid mixture in zone 10.

Referring to FIGS. 2 and 3, an alternative apparatus design is shown. Molten metal 50 is maintained in the heated zone 51 having an opening 52 in the bottom surface thereof. A rotatable shaft 53 extends through heated zone 51 and into an agitation zone 54 wherein an auger 55 is located. The auger 55 has splines 56 extending the length of the auger 55 through the agitation zone 54, determined by the outer auger diameter 67 and the inner wall diameter 62. The agitation zone 54 is surrounded by a cooling jacket 58 having an inlet 59 and an outlet 60. In addition, the agitation zone 54 is surrounded by heat induction coils 61 so that the cooling jacket in combination with the induction coils 61 serve to regulate the heat outflow from the metal alloy composition within agitation zone 54. As best shown in FIG. 3, typical useful sizes of the mixing apparatus comprises an agitation zone with a diameter of $1\frac{1}{4}$ inches, an auger having a diameter of 1 to $1\frac{1}{8}$ inches and grooves between the splines of $1/16$ inch. It is to be understood that these dimensions are only exemplary and that larger or smaller sizes can be employed so long as a high shear rate on the metal can be maintained. The size of opening 52 can be regulated by moving the rotating shaft 53 and auger 55 vertically to open or close opening 52 with baffle 63 located on shaft 53. The heating zone 51 is surrounded by heat induction coils 64 to provide heat to the metal composition 50 therein. The agitation zone 54 is provided with an outlet 66 for removal of the liquid-solid composition containing the primary solid therefrom for subsequent forming.

FIG. 4 is a reproduction of a photomicrograph taken at 50 times magnification of an oil-quenched copper-10 percent tin-2 percent zinc alloy (copper alloy 905). This alloy was formed with the apparatus shown in FIGS. 2 and 3 but with only one auger. The temperature in heating zone 51 was maintained above the liquidus temperature of the alloy, i.e. 999°C. The conditions of temperature and heat in the agitation zone 54 were maintained so that the liquid-primary solid mixture contained about 45 weight percent primary solids. The sample was taken at about 925°C. The spheroidal primary solid metal formations 70 and dendritic secondary solids 71 show an overall metal formation quite different from the normal dendritic network observed

upon cooling this alloy without agitation. The black portion 72 of the primary solids 70 comprise liquid which was entrapped within the primary solids during their formation.

FIG. 5 is a photomicrograph taken at 100 times magnification of a casting made of 10-15 percent lead which was agitated in the apparatus of FIG. 1 but employing only one auger so that the liquid-primary solid mixture contained about 55 weight percent primary solids. The sample was taken at about 191°C. As can be readily observed, the non-dendritic primary solids 73 are surrounded by a secondary solid portion 74 which is dendritic in nature.

FIG. 6 is a reproduction of a photomicrograph taken at 100 times magnification of cast iron containing 2.48 percent carbon and 3.12 percent silicon. The alloy was formed with the apparatus shown in FIGS. 2 and 3. The condition of temperature and heat were maintained so that the liquid-primary solid mixture contained about 35 weight percent primary solids. The sample was taken at about 1280°C. The spheroidal primary solid metal formations 75 are surrounded by dendritic secondary solids 71a. The black portion 72a of the primary solids 75 is entrapped graphite which precipitated during cooling while the darker grey portion 73a comprises liquid which was entrapped within the primary solids during their formation.

Referring to FIG. 7, a convenient means for continuously casting the liquid-solid compositions formed by the process of this invention is shown. The process shown in this figure provides substantial advantage over continuous casting processes of the prior art which continuously cast molten metal alloys. Due to the heat of fusion in the molten metals and their higher temperature, than the liquid-primary solid compositions, they must be rendered solid by heat extraction therefrom at a lower rate than with the liquid-primary solid compositions. If the heat is extracted too quickly from the molten metals, undesirable cracking of the cast product is observed frequently. This results in an undesirably lower throughput rate of metal in the continuous casting apparatus. In addition, undesirable long range segregation (macrosegregation of the alloy constituents) is obtained when continuously casting molten metals. In contrast, when continuously casting the liquid-primary solid compositions of the present process, there is far less heat of fusion available therein which must be removed and therefore much faster throughput rates can be attained without metal cracking. Furthermore, due to the presence of the primary solids, long range segregation is minimized or eliminated. The liquid-solid mixture 76 exiting from the agitation zone 10 is directed to a cooling zone formed by generally cylindrical cooling jacket 77 provided with a cooling fluid outlet 78 and a cooling fluid inlet 79. The agitation zone 10 is constructed and operated in the manner described above such as described with reference to FIG. 1 or FIGS. 2 and 3. The final rod-shaped or cylindrical-shaped solid product 80 containing the primary solids homogeneously dispersed therein is formed by initially providing a plate along the bottom surface of the jacket 77, as indicated by the dotted line 81 in order to initially form a solid within the jacket 77. After the solid is formed, the plate is removed and the solid 80 allowed to move by gravity out of the casing 77. Once this process has been initiated, and interface between the solid 80 and the liquid-solid mixture 82 as

indicated by line 83 is formed. Subsequent to formation within the casing 77, the solid 80 is directly subjected to a spray of cooling liquid as indicated by the arrow 84.

Referring to FIG. 8, an alternative means for collecting and subsequently forming e.g. casting, the products formed by the process of this invention is shown schematically. This process can be used on a batchwise or a continuous basis to form discrete portion of the liquid-primary solid mixture. At or near the exit 40 of the agitation zone, a holding chamber 90 provided with a heating means such as induction heated coils 91 is provided. The agitation zone is constructed and operated in the manner described above such as described with reference to FIG. 1 or FIGS. 2 and 3. Within the holding chamber 90, a generally cylindrical sleeve 92 formed from a heat resistant material is placed to retain a discrete portion of the liquid-primary solid mixture. A discrete portion of the liquid-solid mixture exiting from opening 40 is directed into sleeve 92 as composition 93. In order to maintain the desired fraction solid in the alloy 93, the heating coils 91 are activated in order to maintain the desired temperature. Once the desired amount of metal 93 has been metered into the sleeve 92, it can be formed or cast in any manner desired. Thus, this apparatus provides a convenient means for metering a desired amount of metal which is easily transportable to a subsequent process. For example when, it is desired to form or cast the composition 93, the sleeve 92 and the holding chamber 90 are rotated 90° so that the sleeve 92 can be removed from holding chamber 90 easily while retaining the composition 93 therein. Because of the mechanical characteristics of the liquid-primary solid mixtures formed by the process of this invention, the use of a sleeve 92 eliminates the need for a shot sleeve normally employed in casting and therefore eliminates the problems associated with shot sleeves which result from the need to avoid undue temperature gradients in the metal contained in the shot sleeve. The liquid-primary solid mixture is sufficiently mechanically stable so that when sleeve 92 is removed from holding chamber 90, the liquid-primary solid mixture is removed therewith without substantial leakage. Furthermore, when sleeve 92 is placed in a horizontal position so that the open ends thereof are unsupported, the liquid-primary solid mixture will not leak therefrom. The sleeve 92 and composition 93 are then located between a mold 95 and a pneumatically actuated piston 96 housed within a piston guide 97. The piston 96 can be pneumatically actuated at the desired time, for example by means of air cylinder 98. When actuated, the piston 96 forces the composition 93 within the interior 99 of mold 95 to form the desired product. In one embodiment, a plurality of holding chambers 90 and associated sleeve 92 can be located below the agitation zone exit 66 on a support table (not shown) and they can be progressively indexed below the exit 66 for filling and processed for subsequent casting of the metal therein.

Referring to FIG. 9, an alternative means for casting the compositions formed by the process of this invention is shown schematically. This particular means can be employed batchwise or on a continuous basis to form discrete portions of liquid-primary solid mixtures formed by the process of this invention. As shown in FIG. 9, as liquid-primary solid mixture 100 is exited from the opening 54 of the agitation zone (not shown).

Portions of the liquid-solid mixture 101 would then break off on the main portion 100 by virtue of the gravitational forces thereon and allowed to fall between the die halves 102 and 103. When portion 101 is located between die halves 102 and 103, the die halves 102 and 103 are closed on the composition 101 by actuating the pistons 104 and 105 pneumatically. The pistons 104 and 105 can be actuated by any suitable electronic means such as a photosensitive detector through which the portion 101 passes prior to being positioned between the die halves 102 and 103. After the composition 101 has been formed by cooling, the die halves 102 and 103 are pulled apart and the desired product formed from composition 101 is removed therefrom. A plurality of die halves similar to 102 and 103 can be passed under opening 54 continuously to capture subsequently formed discrete compositions 101 and to cast them in the manner described.

The liquid-solid mixture can, when the desired ratio of liquid-solid has been reached, be cooled rapidly to form a solid slug for easy storage. Later, the slug can be raised to the temperature of the liquid-solid mixture, for the particular ratio of interest, and then cast, as before, using usual techniques. A slug prepared according to the procedure just outlined may possess thixotropic properties depending upon the reheating temperature and the time it is maintained as a liquid-solid either before the slug is fully frozen or after the frozen slug is reheated. Increased time that the slug is maintained as a liquid-solid promotes thixotropic increased behavior of the slug. It can, thus, be fed into a modified die casting machine or other apparatus in apparently solid form. However, shear resulting when this apparently solid slug is forced into a die cavity causes the slug to transform to a material whose properties are more nearly that of a liquid.

Liquid-solid mixtures were prepared employing apparatus like that shown in FIG. 2 and at speeds of about 500 RPM for the auger. Temperature control at the exit 66 of agitation zone 54 was monitored by using a thermocouple. The temperature of the liquid-solid at 50 percent solid for various alloys is given below:

Sn — 10% Pb	210°C
Sn — 15% Pb	195°C
Al — 30% Sn	586°C
Al — 4.5% Cu	633°C

Variations greater or less than the 50 percent primary solid-liquid mixture will result from changes in the temperature values given.

Casting of the partially solidified metal slurry or mixture herein disclosed can be effected by pouring, injection or other means; and the process disclosed is useful for die casting, permanent mold casting, continuous casting, closed die forging, hot pressing, vacuum forming (of that material) and others. The special properties of these slurries suggest that modifications of existing casting processes might usefully be employed. By way of illustration, the effective viscosity of the slurries can be controlled by controlling fraction of primary solid; the high viscosities possible when the instant teachings are employed, result in less metal spraying and air entrapment in die casting and permits higher metal entrance velocities in this casting process. Furthermore, more uniform strength and more dense castings result from the present method.

We claim:

1. The method for forming a homogeneous mixture of a liquid-solid metal composition, wherein said solid comprises discrete degenerate dendrites or nodules, from a first metal composition which, when frozen from its liquid state without agitation forms a dendritic structure, which comprises heating said first metal composition to melt said first metal composition in a first zone, passing the melted first metal composition into at least one agitation zone connected to said first zone, said first zone and agitation zone being sealed to prevent entrainment of gas into said agitation zone, vigorously agitating and cooling the melted first metal composition to solidify a portion thereof and to form primary solids comprising discrete degenerate dendrites or nodules while preventing the formation of interconnected dendritic networks in said agitation zone, said primary solids comprising up to about 65 weight percent of the liquid-solid metal composition and removing said liquid-solid metal composition from said agitation zone at about the same rate that the melted first metal composition is passed into said agitation zone.

2. The method of claim 1 wherein the heated metal composition is cooled to form between 10 and 55 weight percent primary solids.

3. The method of claim 1 wherein the metal composition removed from the agitation zone is cooled to solidify the liquid remaining after the primary solids are formed.

4. The method of claim 3 wherein the heated metal composition is cooled to form between 10 and 55 weight percent primary solids.

5. The method of shaping a homogeneous mixture of a liquid-solid metal composition, wherein said solid comprises discrete degenerate dendrites or nodules, from a first metal composition which, when frozen from its liquid state without agitation forms a dendritic structure, which comprises heating said first metal composition to melt said first metal composition in a first zone, passing the melted first metal composition into at least one agitation zone connected to said first zone, said first zone and agitation zone being sealed to prevent entrainment of gas into said agitation zone, vigorously agitating and cooling the melted first metal composition to solidify a portion thereof and to form primary solids comprising discrete degenerate dendrites or nodules while preventing the formation of interconnected dendritic networks in said agitation zone, said primary solids comprising up to about 65 weight percent of the liquid-solid metal composition, removing said liquid-solid metal composition from said agitation zone at about the same rate that the melted first metal composition is passed into said agitation zone and casting the liquid-solid mixture removed from the agitation zone.

6. The method claim 5 wherein the heated metal composition is cooled to form between 10 and 55 weight percent primary solids prior to being cast.

7. The method of claim 5 wherein the mixture removed from the agitation zone is held in a nonagitated state so that it exhibits thixotropic properties and is liquid-solid in form, and applying force to the thixotropic solid composition, thereby transforming it into a material having properties more nearly that of a liquid to cast said material.

8. The method of claim 5 wherein the liquid-solid mixture is removed continuously from the agitation

zone and is passed continuously through a cooling zone to solidify liquid in said mixture wherein said mixture and the solid obtained by solidifying said mixture is removed continuously from said cooling zone.

9. The method of claim 6 wherein the liquid-solid mixture is removed continuously from the agitation zone and is passed continuously through a cooling zone to solidify liquid in said mixture wherein said mixture and the solid obtained by solidifying said mixture is removed continuously from said cooling zone.

10. The method of claim 5 wherein an amount of the liquid-solid metal composition corresponding to about the amount of said composition to be shaped is removed from the agitation zone and placed in a holding chamber adapted to maintain said composition in a liquid-solid state prior to casting said composition.

11. The method of claim 10 wherein the composition in the holding chamber is cooled to form a solid and said solid is reheated to a temperature wherein the composition is thixotropic or a liquid-solid mixture prior to casting said composition.

12. The method of claim 6 wherein an amount of the liquid-solid metal composition corresponding to about the amount of said composition to be shaped is removed from the agitation zone and placed in a holding chamber adapted to maintain said composition in a liquid-solid state prior to casting said composition.

13. The method of claim 12 wherein the composition in the holding chamber is cooled to form a solid and said solid is reheated to a temperature wherein the composition is thixotropic or a liquid-solid mixture prior to casting said composition.

14. The method of claim 10 wherein the liquid-solid

composition is removed from the holding chamber and is die cast.

15. The method of claim 11 wherein the reheated composition is removed from the holding chamber and is die cast.

16. The method of claim 12 wherein the liquid-solid composition is removed from the holding chamber and is die cast.

17. The method of claim 13 wherein the reheated composition is removed from the holding chamber and is die cast.

18. The method of claim 10 wherein the metal composition removed from the agitation zone is placed in a heat-resistant sleeve within said holding chamber, removing said sleeve and metal composition from the holding chamber and die casting said composition.

19. The method of claim 18 wherein the composition in the holding chamber is cooled to form a solid and said solid is reheated to a temperature wherein the composition is thixotropic or a liquid-solid mixture prior to casting said composition.

20. The method of claim 6 wherein the metal composition removed from the agitation zone is placed in a heat-resistant sleeve within a holding chamber, removing said sleeve and metal composition from the holding chamber and die casting said composition.

21. The method of claim 20 wherein the composition in the holding chamber is cooled to form a solid and said solid is reheated to a temperature wherein the composition is thixotropic or a liquid-solid mixture prior to casting said composition.

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