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(54) **METHOD AND APPARATUS FOR CONTINUOUSLY PREPARING CASTABLE METAL MATRIX COMPOSITE MATERIAL**

Verfahren und Vorrichtung zur kontinuierlichen Herstellung von Metallmatrixverbundmaterial

PROCEDE ET APPAREIL PERMETTANT DE PREPARER UNE MATIERE COMPOSITE COULABLE A MATRICE METALLIQUE

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Description

This invention relates to a method and an apparatus for preparing a composite of a metallic alloy according to the preamble of claim 1 and 11, respectively.

Metal matrix composite materials have gained increasing acceptance as structural materials. Metal matrix composites typically are composed of reinforcing particles such as fibers, grit, powder or the like that are embedded within a metallic matrix. The reinforcement imparts strength, stiffness and other desirable properties to the composite, while the matrix protects the fibers and transfers load within the composite. The two components, matrix and reinforcement, thus cooperate to achieve results improved over what either could provide on its own.

Background Art

Twenty years ago such materials were little more than laboratory curiosities because of very high production costs and their lack of acceptance by designers. More recently, many applications for such materials have been discovered, and their volume of use has increased. The high cost of manufacturing composite materials remains a problem that slows their further application, and there is an ongoing need for manufacturing methods that produce composite materials of acceptable quality at a price that makes them competitive with more common substitutes such as high-strength alloys.

Unreinforced metallic alloys are usually produced by melting and casting procedures. Melting and casting are not easily applied in the production of reinforced composite materials, because the reinforcement particles may chemically react with the molten metal during melting and casting. Another problem is that the molten metal often does not readily wet the surface of the particles, so that mixtures of the two quickly separate or have poor mechanical properties after casting.

In the past, attempts to produce metal alloy-particulate composites by the addition of particulate material to the molten alloy, followed by casting the resulting mixture, have not been particularly successful. It has been postulated that the major difficulty with such an approach is that the most desirable particulates, such as, for example, silicon carbide, are not readily wetted by molten metal alloys. As a result, the introduction and retention of the particles in the livid matrix has been extremely difficult, if not impossible.

An ability to prepare such composites by melting and casting would have important technical and economic advantages, and consequently there have been many attempts to produce such composites it has been suggested that wettability could be achieved by coating the particles with nickel.

Another technique has involved promoting wetting of the refractory particles in the melt by saturating the melt with anions of the refractory particles. Another method involves the addition of such elements as lithium, magnesium, silicon, and calcium into the melt prior to the addition of the refractory particles. Still another method involves the addition of particles of silicon carbide to a vigorously agitated, partially solidified slurry of the alloy, maintained at a temperature well below the liquidus temperature of the alloy so that solid metal particles are present. Still another attempt to improve the wettability of the particulate has involved subjecting large particulate materials and fibers in the melt to ion bombardment, mechanical agitation, vacuum, and heat prior to mixing with the molten alloy, in order to remove moisture, oxygen, adsorbed gases, and surface film therefrom.

The fabrication of aluminum alloy-alumina fiber composites in one approach uses a stirrer blade with a paddle type design, the blade being designed to move very close to the walls of the crucible to induce a high shear and create a vortex for introduction of the fibers into the melt. The process also requires a baffle, which is immersed slightly below the surface of the melt with a tilt angle of about 45° in the direction of flow. The function of the baffle is to divert the flow pattern in the melt and to aid in the entrapment of the fibers below the surface of the melt.

In yet another approach, composites such as aluminum-silicon carbide particulate composites are prepared using the vortex method of dispersion of particles. The particles are pre-heated for 60 minutes at 900°C prior to addition to the melt to aid in their introduction into the melt. The vortex is created by stirring the melt rapidly with a mechanical impeller, which causes a deep vortex to form. The particulate is added through the sides of the vortex in an effort to promote rapid incorporation of the particles into the melt and wetting of the particles by the molten metal. Composites produced by this method tend to have poor bonding of the metal to the particulate, as well as entrapped gas.

In a variation of melting and casting techniques, the reinforcement is provided as a mat of packed material, and the molten metallic alloy is forced under pressure into the spaces remaining. This process, termed infiltration or squeeze casting, produces a composite that is not well bonded internally. Moreover, the process is expensive and difficult to use, since an apparatus specific to each part must be built.

All of these prior melting and casting techniques have drawbacks owing largely to the specialized, costly modifications that must be done to the particulate or the melted alloy, in order to accomplish wetting. Moreover, the techniques have not been successful in manufacturing composite materials for large scale, industrial applications.

Another commercial approach for producing composites having a metal matrix and particulate reinforcement has utilized powder metallurgical techniques. In an example of the powder metallurgical processes,

carefully sized aluminum powder is mixed with silicon carbide particulate in the presence of an organic solvent. A solvent is necessary to prevent a pyrophoric reaction between the aluminum and oxygen in the air. The mixture is poured into drying trays, and the solvent allowed to evaporate over a period of time. The dry, unconsolidated sheets, which are approximately 1 mm thick, are stacked to form a plate of the desired thickness. This fragile stack of sheets is placed into a press and heated to the liquid-solid regime of the matrix, where the metal is slushy in character. The stack is then pressed, consolidating the particles, and forming a solid plate.

In another powder metallurgical process, the silicon carbide particles and aluminum are mixed, as above, but the mixed powder is poured into a cylindrical mold, and consolidated by vacuum hot pressing into a cylindrical billet. Because of the high costs of raw materials, particularly the aluminum powders, and the complexities of the fabrication process, the current costs of the composites discourage their large-scale use in many areas. The powder processes result in considerable segregation of alloying elements in the metallic matrix material, which is undesirable because of its adverse effect on mechanical and physical properties.

Both of the commercial powder metallurgical processes above described result in composites which, while having high moduli and adequate strength, have ductility and formability which are low. The complex superheating and deformation cycle which is required in these processes produce extensive elemental segregation in the matrix, which decreases ductility and prevents the attainment of maximum matrix and composite strengths. A further problem is the retention of the surface oxide which coated the original aluminum powder particles, this serving to further decrease matrix ductility. It would also appear that the oxide coating prevents the complete wetting of the carbide particles, thus further limiting the ultimate composite properties.

U.S. Patent No. 4,473,103 discloses a method for preparing a composite of a metallic alloy reinforced with a preselected volume fraction of nonmetallic particles. It discloses two open topped tanks, one being a mixing tank with deep vortex mixing and the other being essentially a holding station with only sufficient stirring to keep the mixture homogeneous. Vigorous agitation sufficient to promote wetting is carried out only in one of the tanks. The mixing is carried out without any attempt to minimize introduction of gas into the mixture.

There is a continuing need for further improvements using the melting and casting approach to produce metallic composites having good properties. The method and apparatus must also be acceptable in that they produce the composite materials relatively inexpensively, both as compared with other methods of manufacturing composites and with methods of manufacturing competitive materials. The present invention fulfils this need, and further provides related advantages.

Disclosure of the Invention

The present invention provides a method and apparatus for preparing a metallic matrix composite material having wetted nonmetallic refractory ceramic particulate reinforcement dispersed throughout. The process Is continuous, offering the potential for production costs reduced below high costs available with batch production processes. The continuous flow process is suitable for the preparation of composite material for both cast and wrought applications. In the former, the composites can be cast using a wide variety of conventional and unconventional techniques. In the latter, the composite material is formable by standard industrial procedures such as rolling and extrusion into semi-finished products.

In accordance with one embodiment of the invention, a method for preparing a composite of a metallic alloy reinforced with a preselected volume fraction of nonmetallic particles comprises the steps of melting the metallic alloy, adding thereto a preselected volume fraction of nonmetallic -particulate material and mixing the molten metallic alloy with the particulate material in a mixer to wet the molten metal to the particles, under conditions that the particles are distributed throughout the volume of the molten mixture and the particles and the molten metal are sheared past each other to promote wetting of the particles by the metal. The mixing is carried out at a temperature at which the particles do not substantially chemically degrade in the molten metal in the time required to complete the step of mixing; and casting the composite mixture withdrawn from the mixer. According to the novel features, the mixing is carried out in a continuous flow system having multiple stages of mixing comprising at least one tubular mixing vessel having mixing means for mixing the molten alloy and particulate material. The molten alloy and particulate material are continuously fed into one end of a first mixing stage and, the molten alloy and particulate material are mixed in said first mixing stage while ensuring that all of the molten alloy passing through the mixing stage is subjected to the mixing action. The composite mixture formed in the first mixing stage is continuously moved into at least one further mixing stage with the molten alloy and particulate material being further mixed in each further mixing stage while ensuring that all of the composite material passing through the further mixing stage is subjected to the mixing action. The mixing in each stage is carried out with sufficient shear to wet the metal to the particles and while in each stage minimizing the introduction of gas into and minimizing the retention of gas within the mixture of particles and molten metal. A composite mixture for casting is continuously withdrawn from the final mixing stage.

The process of the invention is a continuous flow method for preparing a composite material by mixing

the molten metallic alloy with the reinforcement particles. - Flows of the molten alloy and the particles are introduced into the mixer, where they are mixed under the proper conditions to achieve a homogenous mixture of the wetted particulate in the melt. The flow rates of the molten alloy and the particles are controlled to achieve a preselected total flow rate, and a preselected ratio of particulate to molten metal so that the final solid composite will have a preselected volume fraction of particulate.

Preferably, the metallic material is an aluminum alloy, although other materials such as magnesium alloys can also be used. The nonmetallic particulate material is preferably a metal oxide, metal nitride, metal carbide, metal silicide, or glass. The most preferred composite material is silicon carbide or aluminum oxide particulate reinforcement in an aluminum alloy matrix.

In conventional casting procedures, it is usually desirable to cast molten metal at a high temperature to decrease the viscosity of the metal so that it can be readily cast. However, consideration of reaction of the particulate and molten allow enters into the selection of temperature for the present method. During the mixing and casting steps, the molten metal must not be heated to too high a temperature, or there may be an undesirable reaction between the particulate and the molten metal which degrades the strength of the particulate and the properties of the finished composite. The maximum temperature is therefore chosen so that a significant degree of reaction does not occur between the particles and the metallic melt in the time required to complete processing. For the present approach, the maximum mixing and casting temperature is about 20°C above the liquidus for metallic alloys containing volatile, reactive alloying elements, about 70°C above the liquidus for most common metallic alloys, and about 100°C to about 125°C above the liquidus for metallic alloys containing alloying elements that promote resistance to reaction. However, because of the short duration of mixing, higher temperatures can be tolerated in some circumstances.

A vacuum is applied to the molten mixture of metal and - particulate during the mixing step in the preferred approach. The vacuum reduces the atmospheric gases available for introduction into the melt, and also tends to draw dissolved, entrapped and adsorbed gases out of the melt during mixing. The magnitude of the vacuum is not critical for metal alloys that do not contain volatile constituents such as zinc or magnesium. However, where volatile elements are present, the vacuum is selected so that the volatile elements are not drawn out of the alloy at an unacceptably high rate. The preferred vacuum is found to provide the favourable reduction of gases, while minimizing loss of volatile elements.

The composite material made by the method of the invention has a cast microstructure of the metallic matrix, with particulate distributed generally evenly and homogeneously throughout the cast volume. The particulate is well bonded to the matrix, since the matrix was made to wet the particulate during fabrication. No significant oxide layer is interposed between the particulate and the metallic matrix. The cast composite is particularly suitable for casting and foundry applications where the matrix alloy is a castable composition. For a composite using a wrought alloy matrix, processing is accomplished by known primary forming operations such as rolling and extruding.

Another embodiment of the invention is an apparatus for preparing a continuous flow of a composite of a metallic alloy reinforced with a preselected volume fraction of nonmetallic particles. It includes mixing means for mixing a molten metallic alloy with a particulate material to wet the molten metal to the particles, under conditions that the particles are distributed throughout the volume of the mixture and the particles and the molten metal are sheared past each other to promote wetting of the particles by the metal, and at a temperature at which the particles do not substantially chemically degrade in the molten metal in the - time required to complete the step of mixing. The novel features of the apparatus include mixing means in the form of a continuous flow system having multiple stages of mixing, these multiple stages either (a) at least two vertical tubular mixing vessels with flow connecting conduits therebetween and mixers for mixing the molten alloy and particulate material or (b) at least one elongated, horizontal tubular mixing vessel with mixers for mixing the molten alloy and particulate material. A molten metal feeder continuously introduces a flow of molten metal into one end of the multiple stages of mixing, a particle feeder continuously introduces a flow of particulate into the multiple stages of mixing and flow baffles ensure that all of the molten alloy passing through the multiple stages of mixing is subjected to mixing action. Means are provided for minimizing the introduction of gas into and minimizing the retention of gas within the mixture of particles and molten metal in the mixing vessels, and a vessel is provided for continuously receiving a flow of mixed composite material from the multiple stages of mixing.

The apparatus preferably uses one or multiple stages of mixing. If multiple stages are used, they may be accomplished in either one or multiple chambers. In each stage, the molten metal and the particulate are mixed together, as with a dispersing impeller or other technique for achieving sufficient shear of the molten metal with respect to the particulate to wet the metal to the particulate. Care is taken to prevent air or other adversely reacting gas from interfering with the wetting process, although small amounts of beneficial gases may be introduced into the mixer as needed.

It will now be apparent that the method and apparatus of the present invention present an important and significant advance in the art of manufacturing composite materials. The composite materials are produced economically by apparatus which incorporates the par-

ticulate reinforcement directly into the molten metal, without the need to coat or otherwise treat the particles before incorporation and using conventional metallic alloys. The method is economically competitive with methods of preparing unreinforced alloys, and produces composites much less expensively than do other technologies. Other features and advantages of the present invention will become apparent from the following more detailed discussion, taken in conjunction with the accompanying drawings, which illustrate, by way of example, the principles of the invention.

Brief Description of the Drawings

FIGURE 1 is a schematic side sectional view of a melt in a crucible before, during, and after conventional impeller mixing;
FIGURE 2 is an elevational view of a dispersing impeller;
FIGURE 3 is a side sectional view of the mixing apparatus using a dispersing impeller, with portions broken away for clarity, and with related apparatus shown diagrammatically;
FIGURE 4 is a side sectional view of another mixing apparatus;
FIGURE 5 is a side sectional view of another mixing apparatus; and
FIGURE 6 is a side section view of another mixing apparatus.

Best Mode for Carrying Out the Invention

The present invention is embodied in a process and apparatus for preparing a composite material by incorporating particulate nonmetallic reinforcement into a molten mass of the matrix material. To produce an acceptable composite material, the molten metal must wet the surface of the particulate. If wetting is not achieved, it is difficult to disperse the particulate throughout the mass of metal, since the particulate rises to the surface even after being forced below the surface by a mixer. Unwetted particulate also results in unsatisfactory mechanical properties of the cast solid composite material, especially for particulate matter having a relatively short ratio of length to thickness, also termed the aspect ratio. For particles having a short aspect ratio on the order of 1-5, there must be good bonding at the interface of the particle and the matrix to achieve good strength and stiffness values. Good bonding cannot be readily achieved in the absence of wetting of the molten matrix to the particles.

Wetting of a metal to a particle is a phenomenon involving a solid and a liquid in such intimate contact that the adhesive force between the two phases is greater than the cohesive force within the liquid. Molten metals such as aluminum and aluminum alloys wet and spread on many typical nonmetallic particulate reinforcement materials under the proper conditions, but the presence of certain contaminants at the surface between the metal and the particles inhibits wetting. Specifically, gas and oxides adhered to a surface inhibit wetting of a molten metal to that surface. It is therefore necessary to minimize the presence and effect of gas and oxides otherwise interposed between the molten metal and the particulate in order to permit the molten metal to wet the surface, thereby retaining the particulate within the molten metal during mixing and casting, and promoting good interfacial bonding properties after casting and solidification.

There are several sources of gas in a molten mixture of the metal and particulate that can interfere with wetting of the metal to the particles. Gas is adsorbed on the surface of the particles that are initially provided. Even after thorough cleaning, gases immediately reattach themselves to the surface of the particles, even in high vacuum. These layers inhibit the subsequent wetting. Gas bubbles readily attach themselves to the surfaces of the particulate after immersion in the molten metal, since the surface sites tend to be most favourable for the attachment or nucleation of bubbles.

Gas is present in the molten metal in a dissolved or physically entrained state. Gaseous species are also present as oxides on the surface of the metals. The preferred metal for use in the present invention, aluminum, is well known for the rapid formation of an oxide on the surface of the liquid or solid metal, and this oxide directly inhibits wetting.

Gas can also be introduced into the molten mixture of metal and particulate by the mixing technique used to mix the two together to promote wetting. In the prior practice for mixing, a paddle-type or ship's propeller-type of mixing impeller has been used to promote mixing and wetting of the metal and particulate. The melt is stirred at a high rate to form a vortex above the impeller, and then the particulate is added into the sides or bottom of the vortex. It has been thought that the metal flow along the sides of the vortex promotes mixing.

Instead, it has now been found that the presence of a vortex inhibits wetting, the ultimate objective of the mixing procedure, by incorporating gas into the mixture. Gas is physically drawn into the molten mixture by the vortex, most noticeably when there is a gaseous atmosphere above the melt but also when the mixing is accomplished in vacuum.

FIGURE 1 graphically illustrates the effect of vortex mixing and the incorporation of gas into a composite melt. An experiment was performed to determine the extent of incorporation of gas into the molten mixture. A mixture of aluminum and silicon carbide particulate was melted in a crucible, and line A represents the surface of the melt. The melt was then rapidly stirred in argon with a conventional mixing impeller to generate a vortex at the surface, and line B represents the shape of the surface during mixing while the deep vortex characteristic of rapid stirring of metals is present. When mixing was stopped, the surface level of the melt, represented by

line C, was significantly higher than before mixing, line A. The difference was due to gas that had been drawn into the melt by the vortex and entrapped during the mixing process. This physical entrainment is particularly significant for melts containing solid particulate, since the gas that is drawn into the melt is preferentially retained at the surface between the particulate and the melt. Thus, while mixing can have the beneficial effect of promoting a distribution of the particles in the melt and wetting, the wrong type of mixing ultimately inhibits the wetting.

The mixing action can also nucleate undesirable gas bubbles in the melt in a manner similar to cavitation. Dissolved or entrapped gases are nucleated into bubbles in the region of low pressure immediately behind the blades of an improperly designed mixing impeller due to the reduced pressure there, and the bubbles preferentially attach to the particulate surfaces, also inhibiting wetting.

The mixing process of the present invention minimizes the incorporation of gases into the melt and the retention of adsorbed, dissolved and entrapped gases in the melt, with the result that there is a reduced level of gases in the melt to interfere with wetting of the metal to the particles.

The mixing process also creates a state of high shear rates and forces between the molten metal and the solid particles in the melt. The shear state helps to remove adsorbed gas and gas bubbles from the surface of the particulate by the physical mechanism of scraping and scouring the molten metal against the solid surface, so that contaminants such as gases and oxides are cleaned away. The shear also tends to spread the metal onto the surface, so that the applied shear forces help to overcome the forces otherwise preventing spreading of the metal on the solid surface. The shearing action does not deform or crack the particles, instead shearing the liquid metal rapidly past the particles.

In the preferred approach, a vacuum is applied to the surface of the melt. The vacuum reduces the incorporation of gas into the melt through the surface during mixing. The vacuum also aids in removing gases from the melt. A vacuum need not be used if other techniques are employed to minimize introduction of gas into the molten metal and to minimize retention of gas in the molten metal. One such approach within the scope of the present invention is that of US Patent 5,028,392, issued July 2, 1991.

Preparation of a composite of a metallic alloy, preferably aluminum or an aluminum alloy, reinforced with particles of a nonmetallic material, preferably silicon carbide, begins with melting the aluminum alloy. A wide range of standard wrought, cast, or other aluminum alloys may be used, as, for example, 6061, 2024, 7075, 7079, and A356. There is no known limitation to the type of alloy.

Before the particles are added, it is preferred but not necessary to clean the melt to remove oxides, particles, dissolved gas, and other impurities that inhibit wetting. In one approach, a nonreactive gas such as argon gas, or a mixture of nonreactive gas and reactive gas such as argon and chlorine, is bubbled through the melt in a holding tank for a period of time, as about 15 minutes, before particles are added. The gas bubbles to the surface, carrying with it dissolved and entrapped gases, such as hydrogen gas, that diffuse into the gas bubbles as they rise, and also forcing dross floating in the metal to the surface.

Particles of the nonmetallic refractory ceramic material are added to and mixed with the molten metal. The particles must exhibit a sufficiently low degree of degradation by chemical reaction with the molten metal under the conditions of mixing and casting. That is, a particulate that dissolves into the molten metal under all known conditions is not acceptable, nor is a particulate that forms an undesirable reaction product in contact with the molten metal. On the other hand, most nonmetallics react extensively with molten metals at high temperatures, but in many cases the reaction can be reduced to an acceptable level by controlling the temperature of the molten metal to a temperature whereat there is no substantial degree of reaction during the time required for processing.

The preferred nonmetallic reinforcement materials are metal oxides, metal nitrides, metal carbides, metal silicides, and glasses. Of these, silicon carbide and aluminum oxide are of particular interest, as they are readily procured, are inexpensive, and exhibit the necessary combination of physical properties and reactivity so that desirable composites may be made using the present approach.

The amount of particulate added to the melt may vary substantially, with the maximum amount being dependent upon the ability to stir the melt containing the particles to achieve homogeneity. With increasing amounts of particulate, the melt becomes more viscous and harder to stir. Higher amounts of particulate also provide increased surface area for the retention and stabilization of gas within the melt, limiting the ability to prepare a sound, wetted material. The maximum amount of particulate in aluminum alloys has been found to be about 35 volume percent. The size and shape of the particles may also be varied.

A combination of the molten metal and the particles, prior to mixing, is formed by a convenient method. The particles may be added to the surface of the melt or below the surface, although in the latter case the particles typically rise to the surface unless mixing is conducted simultaneously to achieve partial or complete wetting. The particles can also be added with the pieces of metal before the metal is melted, so that the particles remain with the metal pieces as they are melted to form the melt. This latter procedure is not preferred, as it is desirable to clean the melt prior to addition of the particulate. If the particulate is present during cleaning of the melt, the particulate may be carried to the surface with

the cleaning gas.

The particulate and the molten metal are mixed together for a time sufficient to wet the molten metal to the particles. The mixing is conducted under conditions of high shear strain rate and force to remove gas from the surface of the particulate and to promote wetting. The mixing technique must also avoid the introduction of gas into the melt, and avoid the stabilizing of entrapped and dissolved gas already in the melt.

One approach to mixing uses a dispersing impeller immersed into the melt and operated so as to induce high shears within the melt but a small vortex at the surface of the melt. A dispersing impeller meeting these requirements is illustrated in FIGURE 2. This dispersing impeller 100 includes a dispersing impeller shaft 102 having a plurality of flat blades 104. The blades 104 are not pitched with respect to the direction of rotation, but are angled from about 0 to about 45° from the line perpendicular to the shaft 102. This design serves to draw particulate into the melt while minimizing the appearance of a surface vortex and minimizing gas bubble nucleation in the melt. Tests have demonstrated that this impeller can be rotated at rates of up to at least about 2500 revolutions per minute (rpm) without inducing a significant vortex at the surface of aluminum alloy melts. A high rate of rotation is desirable, as it induces the highest shear rates and forces in the molten mixture and reduces the time required to achieve wetting.

The melt is mixed with the dispersing impeller for a time sufficient to accomplish wetting of the metal to the particulate and to disperse the particulate throughout the metal. Empirically, a total mixing time of about 70 minutes for batch processing systems has been found satisfactory. For a continuous flow system, substantially all of the volume of molten mixture must be subjected to a high shear state at least once. The preferred approach is to have the mixing impeller sized to the molten composite flow channel so that virtually all of the composite material that passes through the channel is stirred by the impeller. Multiple stages of mixing can be provided to ensure that all of the molten material is mixed.

The temperature of mixing should be carefully controlled to avoid adverse chemical reactions between the particles and the molten metal. The maximum temperature of the metal, when in contact with the particles, should not exceed the temperature at which the particles chemically degrade in the molten metal. The maximum temperature is dependent upon the type of alloy used, and may be determined for each alloy. While the molten alloy is in contact with the particulate, the maximum temperature should not be exceeded for any significant period of time.

For example, the maximum temperature is about 20°C above the alloy liquidus temperature for silicon carbide particulate alloys containing significant amounts of reactive constituents such as magnesium, zinc, or lithium. The maximum temperature is about 70°C above the alloy liquidus temperature for common alloys that do not contain large amounts of reactive or stabilizing elements. The maximum temperature is about 100°C to about 125°C above the alloy liquidus where the alloy contains larger amounts of elements that stabilize the melt against reaction, such as silicon. If higher temperatures than those described are used, it may be difficult or impossible to melt, mix and cast the composite material mixture because of increased viscosity due to the presence of dissolved matter.

The maximum temperature also depends upon the reactivity of the particulate, which is determined primarily by its chemical composition. Silicon carbide is relatively reactive, and the preceding principles apply. Aluminum oxide is relatively nonreactive in aluminum and aluminum alloys, and therefore much higher temperatures can be used.

In a prior approach termed rheocasting, the metal and particulate were mixed in the range between the solidus and the liquidus of the alloy. In this range, solid metal is formed in equilibrium with the liquid metal, and the solid metal further increases the viscosity and the shear forces, making the mixing even more effective. However, it has now been found that the use of temperatures substantially below the liquidus results in extensive and undesirable segregation of alloying elements in the metallic phase after the composite is solidified. The material also cannot be readily cast using conventional casting procedures.

The molten mixture is therefore maintained in the temperature range of a minimum temperature where there is substantially no solid metallic phase formed in equilibrium with the liquid metal, to a maximum temperature whereat the particles do not chemically degrade in the molten metal. The minimum temperature is about the liquidus of the molten metal, although lower temperatures can be sustained briefly. Temperature excursions to lower temperatures are not harmful, as long as the melt is cast without a solid metallic phase present. For example, when the particulate or alloying additions are added to the melt, there can be a normal brief depression of the temperature. The temperature must be raised above the liquidus temperature before the melt may be cast. Although permitted for brief periods, such temperature excursions are preferably avoided because of the energy cost in restoring the steady state temperature. The maximum temperature is limited by the onset of degradation of the particulate in the liquid metal. Brief excursions to higher temperatures are permitted, as long as they do not cause significant degradation of the particulate, but such higher temperatures should not be maintained for extended periods of time.

After mixing is complete and the molten composite mixture is withdrawn from the mixing apparatus, the composite can be cast using any convenient casting technique. After the composite has been mixed, the melt is substantially homogeneous and the particles are wetted by the metal so that the particles do not rapidly

float to the surface. If the composite material is held for a substantial period of time, it may be stirred or agitated to prevent segregation of the particles due to density differences, but the stirring should not introduce gas into the melt. Casting need not be accomplished immediately or with a high-rate casting procedure.

The resulting cast material may be made into products by conventional metallurgical procedures. The composite can be annealed and heat treated. It can be hot worked using, for example, extrusion or rolling in conventional apparatus. The final composite can also recast in foundry operations by any acceptable casting procedure.

Figures 3-6 illustrate three embodiments of apparatus for preparing composite materials by the continuous flow process of the invention. Referring to Figure 3, an apparatus 10 includes a mixer 12, a molten metal supply 14 and a particulate feeder 16 that supply the molten matrix alloy and particulate, respectively, to the mixer 12, and a holding furnace 18 that receives the mixed composite material from the mixer 12 and retains it prior to casting.

The mixer 12 includes at least one, and here illustrated two, stages of mixing of the molten metal and the particulate. The molten metal is received from the molten metal supply 14 through a heated conduit 20. The molten metal supply 14 includes a furnace 15 that melts the metallic alloy to be used as the matrix of the Composite material. Preferably, the molten metal in the furnace 14 is continuously cleaned by bubbling an inert gas such as argon, or a mixture of inert and reactive gases such as argon and chlorine, through the molten metal with a lance 22 inserted below the surface. The bubbled gas collects any dissolved or entrapped gas, such as hydrogen and oxygen, that may be present in the melt and removes it to the surface, and also floats dross particles that may be present below the surface of the melt. Molten metal flows from below the surface of the furnace 15 to an evacuated degassing unit 17, where an applied surface vacuum removes entrapped gases remaining from the treatment of the furnace 15. Molten metal flows continuously from below the melt surface of the degassing unit 17 through the conduit 20 to the mixer 12.

Because the vacuum and metal levels may vary, and because it is desirable to control the flow rate of metal with reasonable precision, a metal pump 24 is located in the metal conduit 20. The pump 24 is variable speed, and acts both as a pump and a valve in providing a controllable flow rate of molten metal to the mixer 12.

The particulate feeder 16 is a vacuum extruder or vacuum-locked hopper of the type commercially available. The particulate is typically carefully dried in the feeder 16, to ensure that no moisture reaches the mixer 12. The particulate is fed from the feeder 16 through a particulate conduit 26 to the mixer 12. The flow rate of the particulate is governed by a screw extruder 28 or similar device that is operated by a variable speed motor. By varying the rate of operation of the extruder 28 and the pump 24, a preselected total flow and preselected relative amount of particulate and metal to the mixer 12 can be achieved. The conduit 28 may be heated if necessary, but in most practice heating of the conduit 28 is not required because the amount of particulate is relatively smaller than the amount of metal supplied to the mixer 12.

In the embodiment of Figure 3, the mixer has two stages, each located in a separate chamber 30 and 32. Each chamber 30 is a generally cylindrical, refractory lined steel vessel, with the cylindrical axis vertical. The upper regions of each chamber 30 and 32 are connected to a vacuum pump 34, and pumped to a vacuum of about 30-50 torr. The vacuum reduces the likelihood of introduction of gas into the molten composite material as it is being mixed.

Molten metal enters near the top of the first chamber 30 from the metal conduit 20. The particulate is introduced onto or just under the surface of the metal through the conduit 26. The first chamber 30 contains a vertically mounted impeller 36 generally of the type shown in Figure 2, which enters the chamber 30 through a rotational vacuum fitting 38 and is driven by an external variable speed motor 40. The impeller 36 stirs the particulate into the molten metal, to form the first form of the composite material. Care is taken that gas is not introduced into the molten material, as through a vortex produced by the impeller 36. Wetting of the molten metal to the particulate is achieved by the high shear mixing action.

The outer diameter of the blades of the impeller 36 is slightly less than the inner cylindrical diameter of the chamber 30. The relatively small clearance between the impeller 36 and the inner wall of the chamber 30 ensures that all metal flowing downwardly through the first chamber 30 will be subjected to the mixing action. Little, if any, of the metal can reach the bottom of the chamber 30 without passing through the blades of the impeller 36. To reduce the likelihood that metal could pass directly down the interior walls in the clearance gap, baffles 42 extend inwardly from the interior wall of the chamber 30. The baffles 42 are projections that interrupt the flow down the interior wall and force the metal and particulate mixture back toward the center of the chamber 30 so that it is mixed by the next stage of impeller blades.

The mixed composite material is withdrawn from the bottom end of the first chamber 30 through a composite metal conduit 44. A commercial eddy current conductivity monitor 46 is placed in the conduit 44 to monitor the volume fraction of particulate in the flow of composite material. This information is used in a feedback sense to control the flow rates of the particulate feeder 16 and molten metal supply 14 to achieve the desired volume fraction of particulate in the final composite material.

The composite material enters the second chamber

32 from the conduit 44. The second chamber 32 is structured in a manner similar to the first chamber 30 and the same numbering of elements has been used, except that the flow of composite material molten mixture is upward rather than downward. (This flow direction is not significant, and the flow direction in the second chamber could be made the same as in the first chamber with a different conduit arrangement.) At this stage, a significant fraction of the particulate has been wetted by the molten metal, but it is possible that some may not yet be wetted. Passing the composite material axially through the impeller 36 of the second chamber 32 further mixes the composite material to increase the percentage of wetted surface of the particulate. The principle may be extended to additional stages, in the event that mixing by two stages is insufficient for some particular composite materials.

The mixed composite material is withdrawn from the second chamber 32 through a conduit 48, and conducted to the holding furnace 18. The conduit 48 also contains an eddy current device 50 to measure the amount of particulate in the composite material.

The apparatus of Figure 3 has a two-stage mixer wherein both stages use impeller mixing. Other types of apparatus are possible, and one such alternative embodiment is illustrated in Figure 4.

In an apparatus 60 of Figure 4, the molten metal supply 14, particulate feeder 16, and holding furnace 18 are as previously described. Here, however, the molten metal and the particulate are introduced into an essentially straight cylindrical mixer 62 whose cylindrical axis is horizontal. The wall 64 of the mixer 62 is formed of a nonconducting material such as aluminum oxide. A high frequency induction coil 66 is wound around the exterior of the cylindrical mixer 62. The induction coil 66, when operated, mixes the molten metal and particulate that is flowing from left to right in the view of Figure 4, to produce the composite material. A plurality of stationary baffles 68 project inwardly from the interior wall of the mixer 62, to prevent stratification of the composite mixture in regions where the mixing produced by the induction coil is low. The interior of the mixer 62 is pumped by a vacuum line 70, to reduce the possibility of gas accumulating in the system and being incorporated in the molten composite material. Eddy current monitors 72 to determine the amount of particulate in the molten composite are also provided. Although Figure 4 depicts the mixer 62 as having a relatively short length for the sake of illustration, the mixer 62 is about 6-9 meters in length, with multiple induction coils and sets of baffles.

An apparatus 80 employing a similar horizontal straight line mixer 82 is illustrated in Figure 5. The construction of this mixer 82 is similar to that described previously, except that one or multiple impellers 84 are operated within the mixer 82 to attain mixing. The impellers can be oriented for side impact mixing, as shown, or for axial mixing as was illustrated in Figure 3. In this embodiment, multiple stages of mixing are utilized within a single chamber of mixing. A combination of impeller and induction mixing, or other type of mixing, may be used.

Yet another apparatus 90 is illustrated in Figure 6. The apparatus 90 includes a mixer 92 with impellers 94, but induction mixing could be used. In the apparatus 90, the metal supply 14 is physically above the mixer 92, so that there is a hydrostatic head applied to the metal and composite material within the mixer 92. No vacuum pumping of the mixer 92 is required, as no gas can enter the system. However, great care is required to ensure that gas does not enter through the particulate feeder 16.

The various embodiments of continuous flow apparatus can be used in combination, as for example impeller and induction mixing, as may be required.

It will now be appreciated that the method and apparatus of the present invention produces particulate reinforced composite materials by a melting and casting procedure that is economical and produces high-quality material. Wetting is accomplished by minimizing the effect of gas in the matrix and mixing with a high shear rate. Although particular embodiments of the invention have been described in detail for purposes of illustration, various modifications may be made without departing from the spirit and scope of the invention.

Accordingly, the invention is not to be limited except as by the appended claims.

Claims

1. A method for preparing a composite of a metallic alloy reinforced with a preselected volume fraction of nonmetallic particles, comprising: melting the metallic alloy and adding thereto a preselected volume fraction of nonmetallic particulate material; mixing the molten metallic alloy with the particulate material in a mixer to wet the molten metal to the particles, under conditions that the particles are distributed throughout the volume of the molten mixture and the particles and the molten metal are sheared past each other to promote wetting of the particles by the metal, and at a temperature at which the particles do not substantially chemically degrade in the molten metal in the time required to complete the step of mixing; and casting the composite mixture withdrawn from the mixer,

   characterized by carrying out the mixing in a continuous flow system having multiple stages of mixing comprising at least one tubular mixing vessel (30, 32, 62, 82, 92) having mixing means (36, 66, 84, 94) for mixing the molten alloy and particulate material, in which the molten alloy and particulate material are continuously fed into one end of a first mixing stage (30), mixing the molten alloy and particulate material in said first mixing stage while ensuring that all of the molten alloy passing through the mixing stage is subjected to the mixing action,

continuously moving the composite mixture formed in the first mixing stage into at least one further mixing stage with the molten alloy and particulate material being further mixed in each said further mixing stage while ensuring that all of the composite material passing through the further mixing stage is subjected to the mixing action, with the mixing in each stage being carried out with sufficient shear to wet the metal to the particles and while in each stage minimizing the introduction of gas into and minimizing the retention of gas within the mixture of particles and molten metal, and continuously withdrawing a composite mixture for casting from the final mixing stage.

2. The method of claim 1, characterized in that the multiple mixing stages comprises at least two vertical tubular mixing vessels (30, 32) through which the molten alloy and particulate material continuously, sequentially flow.

3. The method of claim 1, characterized in that the multiple mixing stages comprises at least one elongated, horizontal tubular mixing vessel (62, 82, 92).

4. The method of claim 3, characterized in that the elongated horizontal mixing chamber (62, 82, 92) includes at least two mixing stages.

5. The method of any one of claims 1-4, characterized in that the metallic material is an aluminum alloy.

6. The method of any one of claims 1-5, characterized in that the nonmetallic material is a refractory ceramic selected from the group consisting of a metal oxide, metal nitride, metal carbide, and metal silicide.

7. The method of claim 6, characterized in that the nonmetallic material is selected from the group consisting of silicon carbide, aluminum oxide, boron carbide, silicon nitride, boron nitride and glass.

8. The method of any one of claims 1-7, characterized in that the mixing step utilizes a rotating impeller (36, 84, 94).

9. The method of any one of claims 1-8, characterized in that the step of mixing is conducted with a vacuum applied to the mixture of molten metal and particles.

10. The method of any one of claim 1-9, characterized in that the step of casting is accomplished at a casting temperature sufficiently high that substantially no solid metal is present.

11. Apparatus for preparing a continuous flow of a composite of a metallic alloy reinforced with a preselected volume fraction of nonmetallic particles, comprising: mixing means (12) for mixing a molten metallic alloy with a particulate material to wet the molten metal to the particles, under conditions that the particles are distributed throughout the volume of the mixture and the particles and the molten metal are sheared past each other to promote wetting of the particles by the metal, and at a temperature at which the particles do not substantially chemically degrade in the molten metal in the time required to complete the step of mixing;

characterized in that said mixing means comprises a continuous flow system having multiple stages of mixing, said multiple stages of mixing comprising either (a) at least two vertical tubular mixing vessels (30, 32) with flow connecting conduits (44) therebetween and mixers (36) for mixing the molten alloy and particulate material or (b) at least one elongated, horizontal tubular mixing vessel (62, 82, 92) with mixers (66, 84, 94) for mixing the molten alloy and particulate material, molten metal feeder (14) for continuously introducing a flow of molten metal into one end of the multiple stages of mixing, a particle feeder (16) for continuously introducing a flow of particulate into the multiple stages of mixing, flow baffles (42, 68) to ensure that all of the molten alloy passing through the multiple stages of mixing is subjected to mixing action, means for minimizing the introduction of gas into and minimizing the retention of gas within the mixture of particles and molten metal in the mixing vessels, and a vessel (18) for continuously receiving a flow of mixed composite material from the multiple stages of mixing.

12. The apparatus of claim 11, characterized in that the elongated horizontal mixing vessel (62, 82, 92) includes at least two mixing stages (68).

13. The apparatus of claim 11 or 12, characterized in that the mixing stage includes an impeller (36) that mixes the molten metal and the particulate material together.

14. The apparatus of any one of claims 11-13, characterized in that the mixing stage includes a vacuum pump (34).

15. The apparatus of claim 11, 12 or 14 characterized in that the mixing stages includes a plurality of baffles (42, 68).

Patentansprüche

1. Verfahren zur Herstellung eines Komposits aus einer Metallegierung, die mit einem vorherbestimmten Volumenanteil nichtmetallischer Teilchen ver-

stärkt ist, das umfaßt: Schmelzen der Metallegierung und Zugabe eines vorherbestimmten Volumenanteils an nichtmetallischem, teilchenförmigem Material; Vermischen der geschmolzenen Metallegierung mit dem teilchenförmigen Material in einem Mischer, wodurch die Teilchen mit dem geschmolzenen Metall benetzt werden, unter solchen Bedingungen, daß die Teilchen über das gesamte Volumen der geschmolzenen Mischung verteilt, und die Teilchen und das geschmolzene Metall gegeneinander geschert werden, wodurch die Benetzung der Teilchen mit dem Metall unterstützt wird, und bei einer Temperatur, bei der die Teilchen in dem geschmolzenen Metall in der zur Vervollständigung des Mischungsschritts erforderlichen Zeit im wesentlichen nicht chemisch abgebaut werden; und Gießen der aus dem Mischer entnommenen Kompositmischung,
dadurch **gekennzeichnet**, daß das Mischen in einem kontinuierlichen Flußsystem durchgeführt wird, das mehrere Mischstufen aufweist, umfassend mindestens einen röhrenförmigen Mischkessel (30, 32, 62, 82, 92) mit Mischeinrichtungen (36, 66, 84, 94) zum Vermischen der geschmolzenen Legierung mit dem teilchenförmigen Material, worin die geschmolzene Legierung und das teilchenförmige Material kontinuierlich an einem Ende einer ersten Mischstufe (30) zugeführt werden, sowie durch Vermischen der geschmolzenen Legierung und des teilchenförmigen Materials in der ersten Mischstufe, wobei sichergestellt wird, daß die gesamte geschmolzene Legierung, die durch die Mischstufe hindurchtritt, dem Mischvorgang unterzogen wird, kontinuierliche Überführung der in der ersten Mischstufe gebildeten Kompositmischung in mindestens eine weitere Mischstufe, wobei die geschmolzene Legierung und das teilchenförmige Material in jeder weiteren Mischstufe weiter vermischt wird, wobei sichergestellt wird, daß das gesamte Kompositmaterial, das durch die weitere Mischstufe hindurchtritt, dem Mischvorgang unterzogen wird, wobei das Mischen in jeder Stufe mit ausreichender Scherung durchgeführt wird, daß die Teilchen mit dem Metall benetzt werden, und wobei in jeder Stufe die Einführung von Gas in die und die Zurückhaltung von Gas in der Mischung aus Teilchen und geschmolzenem Metall minimiert wird, und kontinuierliches Entnehmen der Kompositmischung zum Gießen aus der letzten Mischstufe.

2. Verfahren gemäß Anspruch 1, dadurch **gekennzeichnet**, daß die mehreren Mischstufen mindestens zwei röhrenförmige Mischkessel (30, 32) umfassen, durch die die geschmolzene Legierung und das teilchenförmige Material kontinuierlich fortschreitend hindurchfließen.

3. Verfahren gemäß Anspruch 1, dadurch **gekennzeichnet**, daß die mehreren Mischstufen mindestens einen langgestreckten, horizontalen, röhrenförmigen Mischkessel (62, 82, 92) umfassen.

4. Verfahren gemäß Anspruch 3, dadurch **gekennzeichnet**, daß die langgezogene, horizontale Mischkammer (62, 82, 92) mindestens zwei Mischstufen einschließt.

5. Verfahren gemäß mindestens einem der Ansprüche 1 bis 4, dadurch **gekennzeichnet**, daß das Metallmaterial eine Aluminiumlegierung ist.

6. Verfahren gemäß mindestens einem der Ansprüche 1 bis 5, dadurch **gekennzeichnet**, daß das nichtmetallische Material eine feuerfeste Keramik ist, ausgewählt aus einem Metalloxid, Metallnitrid, Metallcarbid und Metallsilicid.

7. Verfahren gemäß Anspruch 6, dadurch **gekennzeichnet**, daß das nichtmetallische Material ausgewählt ist aus Siliciumcarbid, Aluminiumoxid, Borcarbid, Siliciumnitrid, Bornitrid und Glas.

8. Verfahren gemäß mindestens einem der Ansprüche 1 bis 8, dadurch **gekennzeichnet**, daß im Vermischungsschritt ein rotierender Rührflügel (36, 84, 94) verwendet wird.

9. Verfahren gemäß mindestens einem der Ansprüche 1 bis 8, dadurch **gekennzeichnet**, daß der Mischschritt unter einem an die Mischung aus geschmolzenem Metall und Teilchen angelegten Vakuum durchgeführt wird.

10. Verfahren gemäß mindestens einem der Ansprüche 1 bis 9, dadurch **gekennzeichnet**, daß der Gießschritt bei einer ausreichend hohen Gießtemperatur durchgeführt wird, so daß im wesentlichen kein festes Metall vorhanden ist.

11. Vorrichtung zur Herstellung eines kontinuierlichen Flusses eine Komposits aus einer Metallegierung, die mit einem vorherbestimmten Volumenanteil nichtmetallischer Teilchen verstärkt ist, die folgendes umfaßt:
Mischeinrichtungen (12) zum Mischen einer geschmolzenen Metallegierung mit einem teilchenförmigen Material zur Benetzung der Teilchen mit dem geschmolzenen Metall unter solchen Bedingungen, daß die Teilchen über das gesamte Volumen der Mischung verteilt, und die Teilchen und das geschmolzene Metall gegeneinander zur Unterstützung der Benetzung der Teilchen mit dem Metall geschert werden, und bei einer Temperatur, bei der die Teilchen in dem geschmolzenen Metall während der zur Vervollständigung des Misch-

schrittes erforderlichen Zeit weitestgehend nicht chemisch abgebaut werden;
dadurch **gekennzeichnet**, daß die Mischeinrichtung ein kontinuierliches Flußsystem umfaßt, das mehrere Mischstufen aufweist, diese mehreren Mischstufen umfassen entweder (a) mindestens zwei vertikale, röhrenförmige Mischkessel (30, 32) mit dazwischen befindlichen Flußverbindungsleitungen (44), und Mischer (36) zur Vermischung der geschmolzenen Legierung mit dem teilchenförmigen Material, oder (b) mindestens einen langgestreckten, horizontalen, röhrenförmigen Mischkessel (62, 82, 92) mit Mischern (66, 84, 94) zur Vermischung der geschmolzenen Legierung mit dem teilchenförmigen Material, eine Metallschmelzen-Zuführung (14) zur kontinuierlichen Einführung eines Flusses aus geschmolzenem Metall an einem Ende der mehreren Mischstufen, eine Teilchenzuführvorrichtung (16) zur kontinuierlichen Einführung eines Flusses aus teilchenförmigem Material in die mehreren Mischstufen, Flußumlenkbleche (42, 68) zur Sicherstellung, daß die gesamte geschmolzene Legierung, die durch die mehreren Mischstufen hindurchpassiert, dem Mischvorgang unterzogen wird, Einrichtungen zur Minimierung der Einführung von Gas in die und zur Minimierung der Zurückhaltung von Gas in der Mischung aus Teilchen und geschmolzenem Metall in den Mischkesseln, und ein Kessel (18) zur kontinuierlichen Aufnahme eines Flusses aus gemischtem Kompositmaterial aus den mehreren Mischstufen.

12. Vorrichtung gemäß Anspruch 11, dadurch **gekennzeichnet,** daß der langgestreckte, horizontale Mischkessel (62, 82, 92) mindestens zwei Mischstufen (68) einschließt.

13. Vorrichtung gemäß Anspruch 11 oder 12, dadurch **gekennzeichnet**, daß die Mischstufe mindestens einen Rührflügel (36) einschließt, der das geschmolzene Metall mit dem teilchenförmigen Material vermischt.

14. Vorrichtung gemäß mindestens einem der Ansprüche 11 bis 13, dadurch **gekennzeichnet,** daß die Mischstufe eine Vakuumpumpe (34) einschließt.

15. Vorrichtung gemäß Anspruch 11, 12 oder 14, dadurch **gekennzeichnet**, daß die Mischstufen eine Mehrzahl an Umlenkblechen (42, 68) einschließen.

Revendications

1. Procédé pour préparer un composite d'un alliage métallique renforcé avec une fraction volumique présélectionnés de particules non métalliques, consistant: à fondre l'alliage métallique et à y ajouter une fraction volumique présélectionnée de matière particulaire non-métallique;
à mélanger l'alliage métallique à l'état fondu avec la matière particulaire dans un mélangeur afin de mouiller les particules avec le métal à l'état fondu, dans des conditions telles que les particules sont distribuées dans tout le volume du mélange à l'état fondu et les particules et le métal à l'état fondu sont cisaillées en passant les unes devant l'autre afin de favoriser un mouillage des particules par le métal, et à une température à laquelle les particules, pour l'essentiel, ne se dégradent pas chimiquement dans le métal à l'état fondu pendant la durée nécessaire à l'achèvement de l'étape de mélange; et
à couler le mélange composite retiré du mélangeur,
caractérisé en ce que le mélange s'effectue dans un système à circulation continue ayant des étages multiples de mélanges comprenant au moins un récipient tubulaire de mélange (30, 32, 62, 82, 92) possédant des moyens de mélange (36, 66, 84, 94) afin de mélanger l'alliage à l'état fondu et la matière particulaire, dans lequel l'alliage à l'état fondu et la matière particulaire sont introduits en continu à une extrémité d'un premier étage de mélange (30), en ce que l'alliage à l'état fondu et la matière particulaire sont mélangés dans ledit premier étage de mélange tout en assurant que tout l'alliage à l'état fondu traversant l'étage de mélange est soumis à l'action de mélange, en ce que le mélange composite formé dans le premier étage de mélange se déplace constamment dans au moins un étage de mélange supplémentaire, l'alliage à l'état fondu et la matière particulaire étant de plus mélangés dans chacun desdits étages de mélange supplémentaire tout en assurant que toute la matière composite traversant l'étage de mélange supplémentaire est soumise à l'action de mélange, le mélange dans chaque étage étant effectué avec un cisaillement suffisant afin de mouiller les particules avec le métal et tout en minimisant dans chaque étage l'introduction de gaz et en minimisant la rétention de gaz dans le mélange de particules et de métal à l'état fondu, et en ce qu'un mélange composite est retiré en continu en vue d'une coulée de l'étage de mélange final.

2. Procédé selon la revendication 1, caractérisé en ce que les étages de mélanges multiples comprennent au moins deux récipients de mélange tubulaire verticaux (30, 32) à travers lesquels l'alliage à l'état fondu et la matière particulaire s'écoulent en continu et séquentiellement.

3. Procédé selon la revendication 1, caractérisé en ce que les étages de mélanges multiples comprennent au moins un récipient de mélange tubulaire, horizontal et allongé (62, 82, 92).

4. Procédé selon la revendication 3, caractérisé en ce que la chambre de mélange horizontale et allongée (62, 82, 92) comprend au moins deux étages de mélange.

5. Procédé selon l'une quelconque des revendications 1 à 4, caractérisé en ce que la matière métallique est un alliage d'aluminium.

6. Procédé selon l'une quelconque des revendications 1 à 5, caractérisé en ce que la matière non métallique est une céramique réfractaire choisie dans le groupe formé d'un oxyde métallique, d'un nitrure métallique, d'un carbure métallique et d'un siliciure métallique.

7. Procédé selon la revendication 6, caractérisé en ce que la matière non métallique est choisie dans le groupe formé par le carbure de silicium, l'oxyde d'aluminium, le carbure de bore, le nitrure de silicium, le nitrure de bore et le verre.

8. Procédé selon l'une quelconque des revendications 1 à 7, caractérisé en ce que l'état de mélange utilise une hélice tournante (36, 84, 94).

9. Procédé selon l'une quelconque des revendications 1 à 8, caractérisé en ce que l'étape de mélange s'effectue sous un vide appliqué au mélange de métal à l'état fondu et de particules.

10. Procédé selon l'une quelconque des revendications 1 à 9, caractérisé en ce que l'étape de coulée se réalise à une température de coulée suffisamment élevée de façon qu'essentiellement aucun métal solide n'est présent.

11. Appareil pour préparer un écoulement continu d'un composite d'un alliage métallique renforcé avec une fraction volumique présélectionnée de particules non-métalliques, comprenant: des moyens de mélange (12) pour mélanger un alliage métallique à l'état fondu avec une matière particulaire afin de mouiller les particules avec le métal à l'état fondu, dans des conditions telles que les particules sont distribuées dans tout le volume du mélange et les particules et le métal à l'état fondu sont cisaillées en passant les unes devant l'autre afin de favoriser le mouillage des particules par le métal, et à une température à laquelle les particules, pour l'essentiel, ne se dégradent pas chimiquement dans le métal à l'état fondu pendant la durée nécessaire à l'achèvement de l'étape de mélange;

caractérisé en ce que ledit moyen de mélange comprend un système à écoulement continu possédant des étages multiples de mélange, lesdits multiples étages de mélange comprenant soit (a) au moins deux récipients de mélange tubulaires verticaux (30, 32) avec des canalisations d'écoulement les raccordant (44) entre ceux-ci et des mélangeurs (36) pour mélanger l'alliage à l'état fondu et la matière particulaire soit (b) au moins un récipient de mélange tubulaire horizontal et allongé (62, 82, 92) avec des mélangeurs (66, 84, 94) pour mélanger l'alliage à l'état fondu et la matière particulaire, une alimentation en métal à l'état fondu (14) pour introduire en continu un écoulement de métal à l'état fondu à une extrémité des multiples étages de mélange, une alimentation en particule (16) pour introduire en continu un écoulement de matière particulaire dans les multiples étages de mélange, des déflecteurs d'écoulement (42, 68) afin d'assurer que tout l'alliage à l'état fondu qui traverse les multiples étages de mélange est soumis à l'action de mélange, des moyens pour minimiser l'introduction de gaz et pour minimiser la rétention de gaz dans le mélange des particules et du métal à l'état fondu dans les récipients de mélange, et un récipient (18) pour recevoir en continu un écoulement de matière composite mélangée provenant des multiples étages de mélange.

12. Appareil selon la revendication 11, caractérisé en ce que le récipient de mélange horizontal allongé (62, 82, 92) comprend au moins deux étages de mélange (68).

13. Appareil selon la revendication 11 ou 12, caractérisé en ce que l'étage de mélange comprend une hélice (36) qui mélange le métal à l'état fondu et la matière particulaire ensemble.

14. Appareil selon l'une quelconque des revendications 11 à 13, caractérisé en ce que l'étage de mélange comprend une pompe à vide (34).

15. Appareil selon la revendication 11, 12 ou 14 caractérisé en ce que les étages de mélange comprennent une pluralité de déflecteurs (42, 68).

FIG. 1

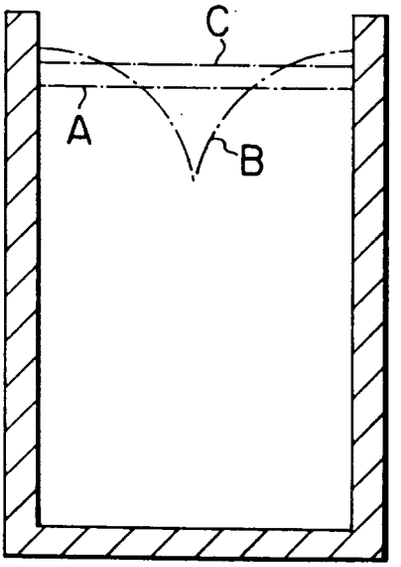
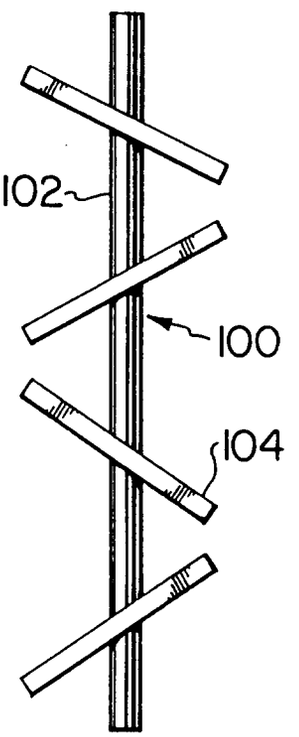


FIG. 2



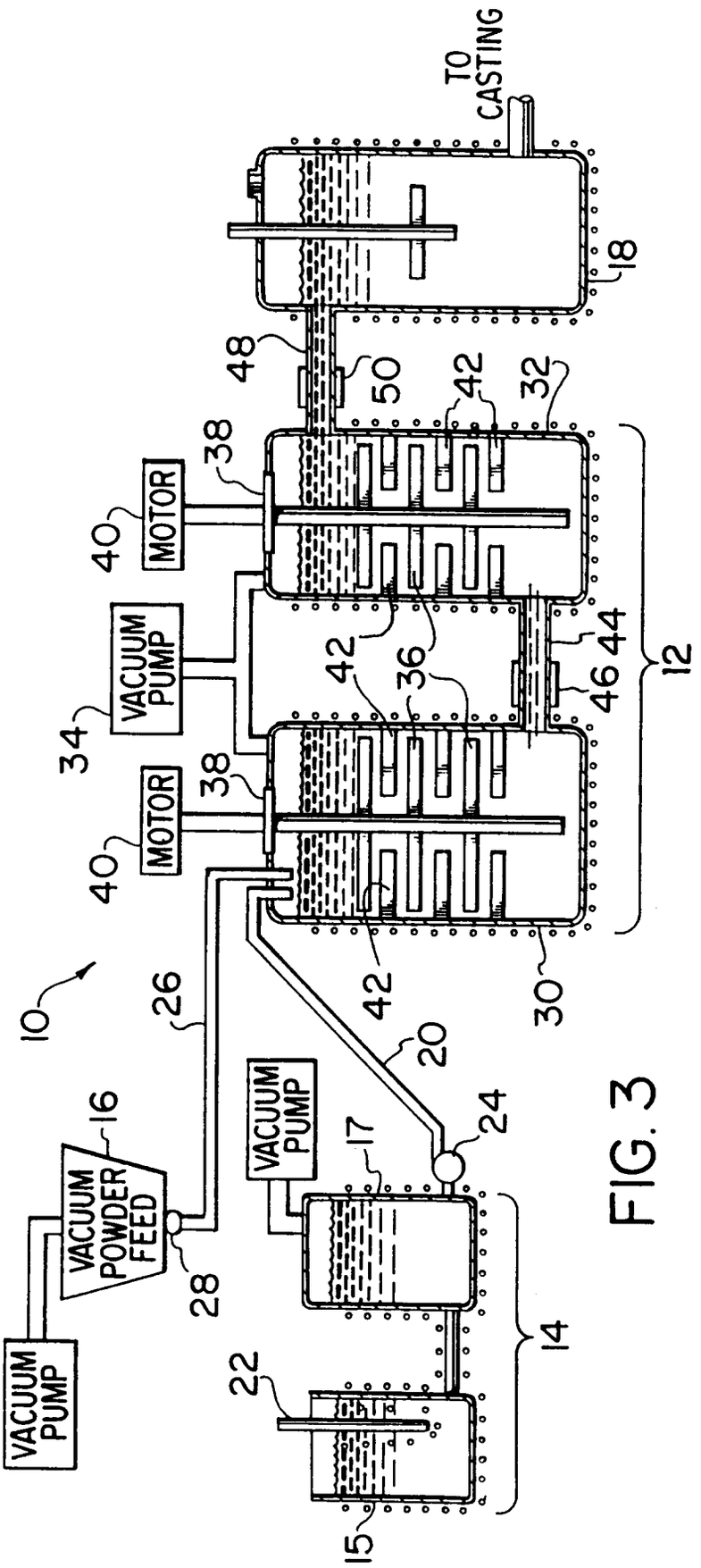

TO CASTING
18
48
50
42
32
38
40
MOTOR
VACUUM PUMP
34
36
44
46
12
30
10
26
20
24
16
VACUUM POWDER FEED
28
VACUUM PUMP
17
14
22
15
VACUUM PUMP

FIG. 3

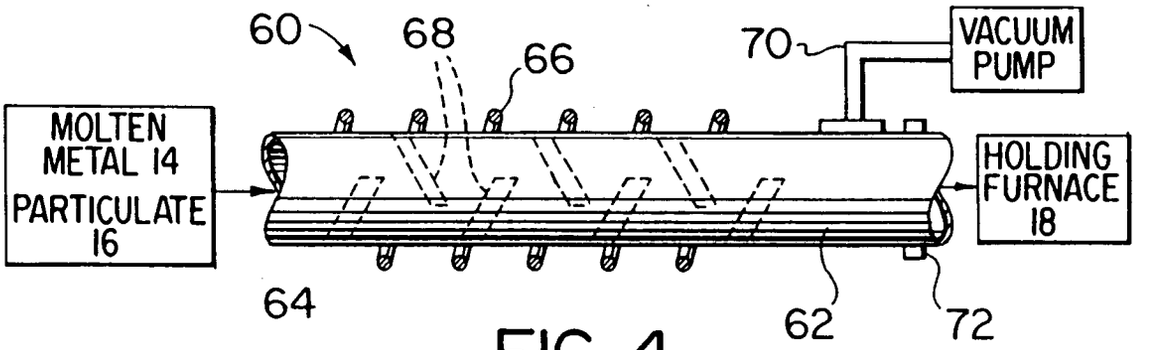


FIG. 4

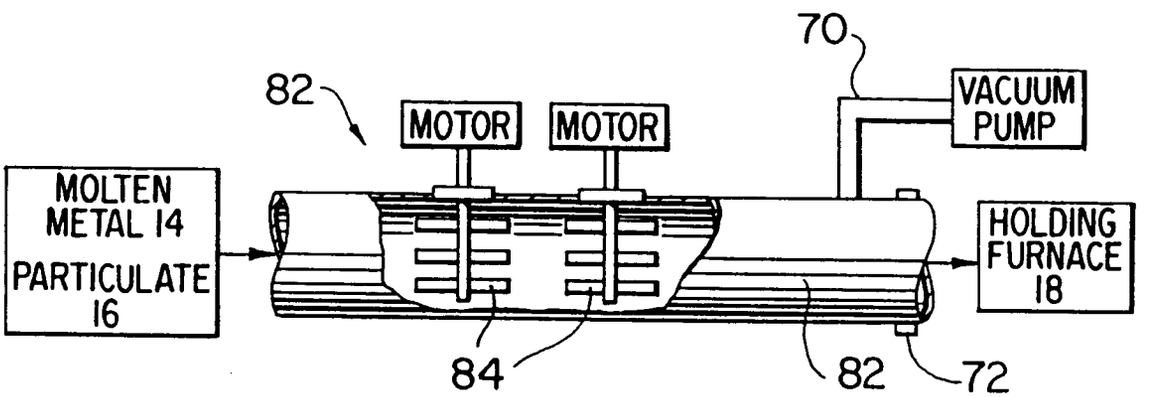


FIG. 5

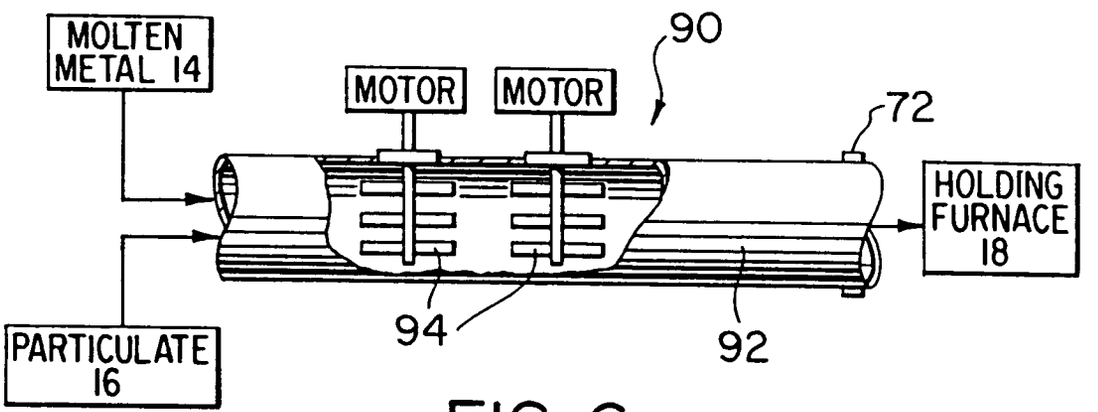


FIG. 6