METHOD AND APPARATUS FOR PRODUCING COMPONENTS FROM METAL AND/OR METAL MATRIX COMPOSITE MATERIALS

Abstract:
Method and apparatus for producing semi-finished or finished products from metal-based material. The apparatus includes a mixing furnace to receive a metal-based material to be formed; temperature control means to maintain the metal-based material in a thixotropic semi-solid state in the mixing furnace; rotatable mixing means operable in the mixing furnace to subject the metal-based material to a mixing and shearing action while imparting a centrifugal force; and supply means to move the material to a delivery site. Optionally, injection means are provided to inject the material from an introduction chamber of a casting machine into a mold or die cavity while the material is in a thixotropic semi-solid state.

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FROM METAL AND/OR METAL MATRIX COMPOSITE MATERIALS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of Australian provisional
application Serial No. 2003905040 filed September 16, 2003 and Australian

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to improvements in a continuous or
semi-continuous processing method and apparatus for producing thixotropic-
conditioned metals such as aluminum and other lightweight metals and/or metal
matrix composite materials to produce ingots of metals or metal parts. Such parts
may be commonly be used for vehicle or general engineering applications.

2. Background Art

It is known from U.S. Patent No. 4,888,054 issued to Pond to
produce metal matrix composite materials including those which contain fly ash or
other reinforcement ceramic particulate material dispersed relatively uniformly in
a metal. The '054 patent discloses that various particulate materials – such as
ceramic balls, microspheres and the like – can be used in the production of metal
matrix composite materials. The relatively uniform mixing of such reinforcement
materials in semi-solid or liquid metal has been successfully achieved when the
particulate material is relatively coarse. But extremely fine particulate materials,
including fine fly ash materials, have proven to be quite difficult to uniformly
disperse in a molten or semi-molten metal material such that they can be cast into
ingot form, or semi-finished or finished product form with a reasonably even
dispersion of the fine particulate material through the metal base material. As disclosed in the '054 patent, which is incorporated herein by reference, the metal base material could include aluminium, magnesium, tin, copper and zinc and alloys thereof.

U.S. Patent No. 5,881,796 issued to Brown et al. discloses an apparatus for producing semi-solid material from molten material by three-dimensional mixing. The semi-solid material is removed from a container by a removal tube that extends through a chamber cover or a side wall. Effectuating semi-solid flow from the container is achieved by vacuum or gravity, or other transfer methods utilizing mechanical means, such as submerged pistons, helical rotors, or other positive displacement actuators. Id., col. 5, II. 57-65. The '796 patent is also incorporated herein by reference.

It is also known that parts produced from metal matrix composites can have light weight, high strength and optimum wear resistance. They can be made at low cost, provided a convenient and effective production method and apparatus are available. Parts which are particularly suited to being produced from metal matrix composite materials include wear resistant vehicle components such as brake drums, brake disc rotors, other brake parts, engine blocks, cylinder heads, con rods, pistons, front end accessory drive parts, belt pulley wheels, auto transmission pump parts, oil pump bodies, rotors, scrolls, and other rotary compressor parts used in air conditioning, refrigeration systems, and any other component in which wear resistance may be a desirable property.

Many of these parts are currently made from cast iron or a hypereutectic aluminium alloy which contains free silicon. These materials suffer from certain disadvantages, such as:

1. cast iron components are heavy and susceptible to corrosion; and
2. High silicon content aluminium alloy components are difficult and expensive to machine because the silicon rich constituents of high silicon content parts can cause interference with a tool path when machining to final dimensions.

Against this background, semi-solid metal processing involves semi-solid slurries in which non-dendritic solid particles are dispersed in a liquid matrix. Z. Fan, SEMI-SOLID METAL PROCESSING, Int'l Materials Reviews, Vol. 47, No. 2 (2002). It is known that when a dendritic structure is broken up, the partially solidified alloy has the fluidity of machine oil and exhibits thixotropic behavior. Id. It is also recognized that rheocasting involves the application of shearing during solidification to produce a non-dendritic semi-solid slurry that can be transferred directly into a mold or die to give a final product. Id. That paper is incorporated herein by reference.

SUMMARY OF THE INVENTION

One objective of the present invention is to provide a method and apparatus for the production of metals and/or metal-based materials and/or metal matrix composite materials (collectively referenced herein – unless the context suggests otherwise – as “metal-based materials”) which have a fine globular or spherical micro structure in an effective and economical manner, so that dross and otherwise wasted material are minimized.

Accordingly, in one aspect, the present invention provides a method of producing semi-finished or finished parts from such metal-based materials. The method includes the steps of:

(i) maintaining a metal-based material in a mixing furnace in a thixotropic semi-solid state (a liquid-like slurry);

(ii) subjecting the material to a continuous shearing and mixing action and a centrifugal force while in a thixotropic semi-solid state state within the mixing furnace to form a fine,
globular microstructure (down to about 0.5 microns in diameter);

(iii) delivering the material involutely from the mixing furnace while in the thixotropic semi-solid state to a delivery site, such as a casting head or into the introduction chamber of a molding machine; and

(iv) transporting the material in the thixotropic semi-solid state into a mold or die cavity of the molding machine from the delivery site to form the semi-finished or finished part or parts.

Preferably, the finished or semi-finished part or parts exiting the molding machine are as near net shape as possible to minimize further machining requirements.

In accordance with a particularly preferred embodiment, metal matrix composite materials are used to form the semi-finished or finished parts. A particulate material may be introduced into the mixing furnace while the metal-based material is subjected to a continuous shearing and mixing action and turbulence to form a metal matrix composite material. The particulate is mixed substantially evenly through the melt.

In accordance with a second aspect of the present invention, there is provided an apparatus for producing semi-finished or finished parts from the metal-based materials. The apparatus includes:

(i) a mixing furnace having a mixing region to receive a metal-based material;

(ii) temperature control means associated with the mixing furnace to maintain the material in a thixotropic semi-solid state;
(iii) rotatable mixing means operable in the mixing furnace to subject the material in the thixotropic semi-solid state to a shearing and mixing action and centrifugal force, which may cause the formation of small solid particles which entrap a liquid phase therewithin, the particles probably being caused in part by a rapid coalescence of broken dendritic arms; and

(iv) supply means to propel the material involutely in the thixotropic semi-solid state from the mixing furnace to a delivery site, such as an introduction chamber of a molding machine; and/or

(v) injection means to move the material from the introduction chamber into at least one mold or die cavity of the molding machine while in the thixotropic semi-solid state.

Accordingly, one objective of the present invention is to provide a rotatable shearing and mixing means that will satisfactorily mix a fine particulate material such as fine fly ash into a molten metal or metal-based material with adequate dispersion of the particulate material through the sheared melt. It will be appreciated that the mixer in accordance with this invention may also be used with coarser particulate materials that might be satisfactorily mixed with other equipment.

Preferably, the apparatus when used to produce parts from a metal matrix composite material, further includes delivery means to meter a desired volume of particulate material into the mixing furnace to form a metal matrix composite material so that the particulate material is substantially evenly distributed through the metal.

The present invention is particularly adapted to processing light weight metals such as superplastic alloys, aluminium, magnesium, tin, copper and zinc and alloys of the aforesaid metals. However, it is not limited to such metals. Other heavier metals including brass can also be processed as described herein.
invention is also particularly adapted to producing parts from metal matrix composite materials, but is not limited thereto. In particular, processing metals to form a fine, globular microstructure therein improves their performance in producing sound die cast parts.

BRIEF DESCRIPTION OF THE DRAWINGS

A further understanding of the present invention will be apparent from the following description of various embodiments given in relation to the accompanying drawings, in which:

FIGURE 1 is a schematic flow diagram of process steps that may be taken in practicing the disclosed invention;

FIGURE 2 is a schematic drawing of the disclosed apparatus constructed in accordance with a first embodiment;

FIGURE 3 is a view similar to Figure 2 showing a second embodiment;

FIGURES 4 and 4a are cross-sectional views of a mixing furnace and a representative delivery site;

FIGURE 5 is a cross-sectional side view of an alternate embodiment of the mixing furnace depicted in Figure 4a;

FIGURE 6 is a plan view, with certain parts omitted for clarity, of the shearing, mixing and impelling device shown in Figure 5 that imparts a centrifugal force to the melt;

FIGURE 7a is a perspective view (partially broken away) of the mixing furnace which contains the mixing device;
FIGURE 7b is a top view thereof;

FIGURE 7c is a side view thereof;

FIGURE 7d is another side view thereof;

FIGURE 7e is a sectional view taken along the line A-A of Figure 7c;

FIGURE 7f is a sectional view taken along the line B-B of Figure 7d;

and

FIGURE 7g is a sectional view taken along the line C-C of Figure 7c.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

Before turning to the process steps that are schematically illustrated in Figure 1, it will be helpful to consider details of the apparatus that is involved in practicing those steps.

Referring first to the drawings, an apparatus according to this invention may be constructed as shown in Figures 2 and 3. The apparatus includes a primary holding furnace 30, that in one preferred aspect, may receive recycled lightweight metal in the molten state delivered at 31 from recyclers of such metal. Alternatively, furnace 30 may be constructed to melt such metal material from the solid state – either from ingots or the like or from scrap solid metal material. Typically the metal will be aluminium or aluminium alloys, but may also include other metals and their alloys, including magnesium, tin, copper, and zinc. Collectively alternative source materials are referred to herein as “metal-based materials.”

The primary holding furnace 30 includes a rotating mixing and device 32 and further includes means 33 to deliver molten metal-based material to a mixing furnace 10.
Optionally, the mixing and shearing furnace 10 includes heating means and/or cooling means (not shown) to ensure that the material in a mixing region 34 is maintained in a thixotropic semi-solid state. The nature and effect of the heating and/or cooling means will depend upon the state of the material supplied to the mixing furnace 10. Generally, the term “thixotropic” refers to “the ability of certain colloidal gels (or slurries) to liquify when agitated (as by shaking . . . ) and to return to the gel form when at rest.” HAWLEY’S CONDENSED DICTIONARY, p. 1152 (7th Ed. 1987). As used in this definition, the term “gel” includes “a colloid in which the dispersed phase has combined with the continuous phase to produce a viscous jelly-like product.” Id., p. 555 (sometimes referred to herein as a “slurry”). The British Standards Institution defines thixotropy as a “decrease in viscosity under stress, followed by a gradual return when the stress is removed.” In the metallurgical context, semi-solid metal alloys are thixotropic. The slurry viscosity is shear-rate and time-dependent provided the microstructure in the semi-solid state is nondendritic. T.Y. Liu, et al., “Rapid Compression of Aluminum Alloys and Its Relationship to Thixoformability”, 34A Metallurgical And Materials Transactions A, p. 1545, July 2003 (incorporated herein by reference).

The mixing and shearing furnace 10 includes a rotatable mixing and shearing device 16 which may be constructed similarly to that which is shown and described hereinafter with reference to Figures 4 and 5. The stirring and shearing action applied to the thixotropic metal-based material in the mixing region conditions the microstructure of the material to a fine, globular state. The material in this state (whether or not it contains particulate material mixed evenly through it) has improved capability for being die cast to produce sound die cast parts with thinner sections than has been possible to date with conventional processing techniques. Without wishing to be bound by any particular theory, it is thought that the ability to make parts of a thinner section is explained by a continuous reconditioning of the metal that is transported to a delivery site, in combination with a shearing action that imparts high velocity to the melt that is propelled peripherally and involutely in the form of fine, liquid-filled particles that may occupy a cavity in a delivery site with a high packing density.
Particulate delivery means 35 is provided to deliver the desired particulate material to the mixing region 34, specifically to a region of high shear created by the blades or impellers of the mixing and shearing device 16. Stirring of the metal in a thixotropic state in the mixing region 34 improves the globular microstructure of the metal and enables moldings or die cast parts having thinner wall sections to be made. Further, enhanced material properties result following solidification of the cast or molded product. The ability to mix, relatively uniformly, the particulate material (typically ceramic particles or fly ash particles) into the metal in a thixotropic state is a supplementary benefit. This allows the production of metal, metal alloy or metal matrix composite materials, or end products made from such materials with an optimum microstructure exhibiting the best possible properties.

A flow path 36 may be provided from the mixing region 34. Optionally, the flow path 36 includes pumping means 37 (Figure 2) to deliver the metal-based material in the thixotropic state directly, for example, to a delivery site such as the introduction chamber 38 of a pressure die casting machine 39. A “Vision 66 N Buhler” die casting machine manufactured and marketed by Buhler AG is believed to be suitable in the performance of the present invention.

Other squeeze die casting process machines might also be employed where semi-solid metal is introduced without turbulence into die cavities. High pressures are maintained throughout the solidification process to produce sound and heat treatable parts.

In an alternative arrangement, the pumping means 37 delivers the metal-based materials in the thixotropic state to an intermediate holding furnace (not shown). This furnace may include an additional mixing and shearing device which may be constructed similar to the mixing device 16 to continue to stir or subject the thixotropic material to shear forces, before being transferred via a further flow passage and pumping means to, for example, the introduction chamber 38 of the pressure die casting machine 39.
The pressure die casting machine 39 includes a single die or mold cavity. Optionally, the machine includes multiple molds or die cavities, whereby multiple parts might be produced. It will be recognized that the flow passages 36 might have associated with them heating/cooling means to ensure that the material carried by the flow passages is kept in a thixotropic state. Similarly, the introduction chamber 38 of the pressure die casting machine 39 may have heating/cooling means.

The pumping means can be any suitable means for moving metal or metal composite materials in a thixotropic state along the desired flow path and may include electromagnetic, piston, screw or similar pumping means.

In a preferred embodiment (Figs. 4, 4a), the discharge line from the mixing furnace 10 exits involutely or tangentially from the mixing furnace, such that the mixing rotor 16 serves as a turbine or centrifugal pump to impel the thixotropic metal-based material towards a desired delivery site, such as a die casting machine 39. Optionally, the blades are removable from the mixing furnace 10 to allow their orientation to be reconfigured. In this way, any wear along their edges can be uniformly distributed among the four edges because the blades can be inverted laterally or longitudinally. Thus, what was a leading edge can, after reconfiguration, become a trailing edge, and vice versa. A preferred blade composition is titanium or an alloy thereof.

The discharge line 36, preferably shaped as a curved involute, is made of an appropriate material such as titanium, or a titanium-containing metal alloy with at least 50% titanium content by mass. It may have a round cross section. As used herein, unless the context suggests otherwise, the term “titanium” includes titanium metal or a titanium-containing alloy. Alternatively, the discharge casing may have a cross section which is rectangular in shape, thereby enabling it to be assembled from flat sheet pieces that are welded together, through which the material is freely discharged into large volume casting molds.
Preferably, the discharge line 36 is heated to a temperature (such as 585°C) between the solidus and liquidus of the metal-based material to ensure that its contents do not freeze after emerging from the mixing furnace 10 toward a delivery site, such as for example, a die casting machine or a smelter casthouse. In this way, the metal-based materials may be continuously recirculated so as to prevent the metal from losing its thixotropic characteristics. Such characteristics may be lost if the semi-solid material becomes stationary in the discharge line. In practice, the metal remains in motion on the outer periphery of the mixing furnace into the involute curve before becoming rechanneled into the discharge line at the urging of centrifugal force imparted by the mixing rotor 16.

The pumping and storage system maintains the metal within a thixotropic semi-solid temperature range so that a casting made by the process exhibits not only the desired mechanical properties but also the lowest shrinkage and the closest possible approach to a desired net molding shape. This lowest possible temperature approach has a supplementary benefit of prolonging die life, since operation in the semi-solid temperature range reduces surface cracking, soldering and die erosion. Moreover, viscous alloys can be handled using the disclosed process because the metal is pumped rather than ladled, so alloys which previously were not suitable for die casting can now be used.

Figure 3 shows an alternative arrangement, but similar to that which is shown in Figure 2. In this embodiment, the mixing furnace 10 includes a series of cooling fins 40 around its periphery and base to assist with cooling of molten metal to its thixotropic state. If desired, cooling by various means, such as fan means (not shown) might also be provided to increase the cooling effect. As is further illustrated, a return flow path 41 including pumping means 42 is provided to return thixotropic material from the die introduction chamber 38 that is not required in a particular casting process step, to the mixing furnace 10.

Alternatively, if an intermediate holding furnace is provided between the furnace 10 and the casting machine 39, unused material can be returned via the intermediate holding furnace.
Referring to Figure 5, one mixing furnace embodiment 10 is illustrated. The mixing furnace 10 includes a fabricated container 11, preferably made from a suitable material such as titanium or a titanium-containing metal having a base wall 12 and a cylindrical upright side wall 13 connected to the base wall 12. A horizontal radially outwardly extending flange 14 may be provided adjacent the upper end 15 of the container 11. Heating means such as electrical elements or induction heaters (or any other suitable heating means) may be provided outwardly of, but adjacent to the wall 13 to maintain the metal within the container in a thixotropic state during a mixing operation. As discussed above, cooling means such as cooling fins 40 might also be required if the metal supplied to the furnace is initially molten (liquid) to reduce the metal to a temperature range in which it will be in a thixotropic (semi-solid) state. The cooling means might include fans cooperating with the cooling fins 40. The cooling/heating means have not been illustrated in the drawing for clarity. Similarly, the lifting and handling means are not illustrated, as they are within the knowledge of the skilled artisan.

The apparatus includes a rotatable mixing member 16 including a rotatable shaft 17 which, in Figure 6, would be rotated, preferably, in a clockwise direction (arrow A). An adjustable drive means (not shown) is provided for the shaft 17 such that the shaft may be selectably rotated to cause the blades to travel at a blade speed measured at an outer diameter of between about 3 meters/sec and about 10 meters/sec as the particulate material is metered onto a rolling surface of the semi-solid metal by a delivery means illustrated schematically at 35 (Fig. 5). The particulate material delivery means 35 is desirably positioned so as to deposit the particulate material to a region of greatest shear on the surface of the semi-solid material, i.e., adjacent to the peripheral path traveled by the blades 21. The delivery means 35 are further controlled such that the particulate material on the surface of the molten metal does not exceed about 30 mm in depth.

By suitable adjustment of the distance between the periphery of the blades and the side walls of the mixing furnace and rotation speed, the needs of different applications can be met. These include for example, the desire to achieve a small versus a large grain size, or provide a pressure-restricted flow to a die
casting machine, versus a free discharge operation for feeding an ingot casting machine.

The rotatable mixing device 16 includes a central body section 18 with a cylindrical outer wall 19 and a closed base wall 20. The body section 18 is provided to occupy the central zone of the mixing chamber which otherwise would be occupied by semi-solid metal that would have low or no velocity. It therefore would not be readily subjected to particulate mixing and a shearing effect. The relative dimensions of the central body section are such that the section has a cylindrical surface with a diameter that is at least 10% of the internal diameter of the mixing region of the mixing furnace. Preferably, the diameter of the central body section is between 15% and 35% of the diameter of the mixing region.

As best shown in Figures 5 and 6, uniformly spaced (radially and circumferentially) blade members 21 are provided such that they are rotated in an upright configuration about the axis of rotation 22 defined by the shaft 17. Each blade member 21 is formed by a flat sheet that in a preferred embodiment is approximately 70 mm wide, 10 mm thick and 435 mm in length. The blade members 21 are preferably angled relative to the circumferential direction at an angle of 30 degrees ± 7 degrees (preferably 30 degrees) such that a trailing edge zone 23 is disposed closest to an inner wall surface 24 of the container upright side wall 13. Preferably the trailing edge zone 23 of each blade member is located between 10 and 30 mm from the inner container surface 24. Still more preferably, this spacing is about 20 mm. As can be seen in Figure 5, each blade member 21 is connected to a mid to lower region of the central body section 18 by support arms 27 such that the upper ends 25 of the blade members 21 are located below the upper end of the central body section 18 and just below the upper surface of the metal-based material when a mixing operation is undertaken. The lower ends 26 of each of the blade members 21 are spaced only a short distance above the base of the container 12.

It has been found that the angle of the upright blade members and the minimum distance between the blade members and the inner container wall influence
the centrifugal forces imparted to the melt and the shear and mixing effect between the blades and the container wall and thus promote a suitable, relatively uniform mixing in of the particulate material and its distribution through the molten metal-based material.

In an alternative embodiment, a series of holes may be provided in one or more of the blade members 21 so as to cause a further shearing action in the mixing furnace as the blades rotate. Alternatively, bars (preferably of titanium or an alloy thereof) could be arranged lengthwise and parallel to a major axis (vertically). In this embodiment, the bars would be detachably affixed for ease of maintenance so that they are vertically aligned perpendicularly to a radially outward direction. In another embodiment, some or all of the blades are replaced by a mesh-like material, such as a wire mesh.

Figures 7a to 7g illustrate a further modified mixing furnace 10 which contains a mixing and shearing device 16. In Figure 7c, the function of the pipe 70 and the flange 71 shown at the base of the mixing furnace 10 is to allow molten metal-based material contained within the furnace 10 to be drained from the mixing furnace 10 through a gate or stop valve (not shown) attached to the flange 71. The top of the furnace 10 may be formed by a removable lid 72 that can be bolted to a lower furnace section 73, whereby any desired atmosphere (gas) may be supplied over the material in the furnace via pipe 63. The removable lid 72 allows the mixing and shearing device 16 to be withdrawn from the furnace 10 for maintenance. The return pipe 41 on the right side of Figure 7f may be in practice, be proportionally larger than depicted.

The funnel 35 shown on the left of Figures 7c and 7g allow particles to be fed into the furnace 10 at a position adjacent to the passage of the paddle or blade members 21 where the highest shear conditions are likely to be experienced by the semi-solid metal-based matrix material in the furnace 10. In practice, the pipe leading from the funnel 35 need not to be as large as depicted in diameter as depicted in the drawings.
As with the embodiment of Figures 4, 4a, the involute discharge passage 64 leading to the flow passage 36 exits the mixing furnace 10 approximately midway between its base and its top where the pressure of the thixotropic metal or metal matrix material is likely to be at or approaching its highest. As illustrated in Figures 7a to 7g, the involute discharge passage 64 may be square or rectangular in cross-section. The paddles or blades 21 of the mixing and shearing device 16 may extend from a position adjacent the base wall 12 to a position adjacent the top wall 74.

In operation, as indicated earlier, there may usefully be provided, in alternate embodiments of the system, heat dissipation cooling fins around the perimeter of the furnace. Additionally, an area may be provided for installation of an induction heating coil for rapid heating if temperature correction is required.

Reference will now be made to the process steps that are practiced in using the disclosed apparatus. They are schematically illustrated in Figure 1. In this process illustration, molten aluminium or aluminium alloy is conveniently supplied at 15 via a recycler of such metal material. The aluminum may be in form of pure aluminum, or an aluminum-containing metal alloy with at least 50% of aluminum content by mass. Other examples of source materials include magnesium, tin, copper, zinc and alloys and mixtures thereof. Alternatively, molten aluminium might be produced as part of the process from solid material (either recycled or not). The molten metal material is supplied to a primary holding furnace 30 from whence it is delivered in liquid form to a mixing furnace 10. The mixing furnace 10 is arranged to cool and then maintain the metal in its thixotropic state. In the mixing furnace 10, ceramic particulate material or fly ash material in metered quantities are supplied and mixed into the thixotropic metal-based material formed in the furnace 10. This composite metal matrix material, still in the thixotropic state, may be delivered to an intermediate holding furnace 50 and from there delivered to a desired delivery site, such as a high pressure die casting machine 39.

The parts produced by the high pressure die casting machine may be inspected, trimmed and machined to a finished product as required and then
packaged and shipped to an end customer as may be required via steps 51, 52 and 53. Any reject or scrap material is minimized because it may be returned as solid or semi-solid material to an intermediate of the mixing furnace for reprocessing.

In accordance with the invention disclosed herein, the technology so described provides a lower cost, more economical and more efficient process than has been available in the prior art.

Thus, there has been described a furnace in which a stirrer rotates between smooth walls. This action stirs and subjects a cooling metal-based mix to a mixing and shearing action that enables thixotropic, substantially non-dendritic, semi-solid alloys to be produced. The stirrer includes an array of blades made of an appropriate material that rotate within a central closed furnace and subject the melt to centrifugal force. The furnace may be heated or cooled. The blades promote a complex, three-dimensional movement of the metal-based material, and provide a turbine action or impeller-like pumping force that urges the effluent to a delivery site located outside the mixing furnace.

As a result of recycling and continuous rejuvenation of the metal-based material, material loss is low (e.g., below 2%). In contrast, prior art approaches usually involve an allowance for material loss in a die-casting plant, which is about 2-3% of the metal consumed.

While embodiments of the invention have been illustrated and described, it is not intended that these embodiments illustrate and describe all possible forms of the invention. Rather, the words used in the specification are words of description rather than limitation, and it is understood that various changes may be made without departing from the spirit and scope of the invention.
WHAT IS CLAIMED IS:

1. A method of producing semi-finished or finished products from a metal-based material, the method including the steps of:
   (i) maintaining the material in a mixing furnace in a thixotropic semi-solid state;
   (ii) subjecting the material to a continuous shearing and mixing action and centrifugal force while in the thixotropic semi-solid state within the mixing furnace to form at least in part a fine, globular microstructure; and
   (iii) delivering the material involutely from the mixing furnace while in the thixotropic semi-solid state to a delivery site for solidification.

2. A method according to claim 1 including stirring the metal-based material in the thixotropic semi-solid state within the mixing furnace with shearing and mixing means acting about an upright axis to provide the continuous shearing action, the material in the thixotropic semi-solid state being delivered tangentially through discharge means leading from the mixing furnace under forces applied by the shearing and mixing means.

3. A method according to claim 1 wherein the metal-based material includes a metal matrix composite material, the method further including the step of introducing a particulate material into the mixing furnace while the metal-based material is subjected to the continuous shearing and mixing action to form the metal matrix composite material therein, the particulate material being mixed substantially evenly through the metal matrix composite material.

4. A method according to claim 1 wherein the metal in the metal-based material selected from the group consisting of superplastic alloys, aluminium, magnesium, tin, copper, zinc, alloys of the aforesaid metals, and mixtures thereof.
5. A method according to claim 3 wherein the particulate material is selected from the group consisting of ceramic balls, ceramic particles, micro spheres, fly ash, and mixtures thereof.

6. An apparatus for producing semi-finished or finished parts from a metal-based material, the apparatus including:
   i)  a mixing furnace to receive a metal-based material;
   ii) temperature control means associated with the mixing furnace to maintain the material in a thixotropic semi-solid state;
   iii) rotatable mixing and shearing and propelling means operable in the mixing furnace to subject the material in the thixotropic semi-solid state to a shearing and mixing action and a centrifugal force;
   iv) supply means to duct the material involutely in the thixotropic semi-solid state from the mixing furnace to a delivery site for solidification into a near-net shape.

7. An apparatus according to claim 6 further including delivery means to meter a desired volume of particulate material into the mixing furnace to form the metal-based material therein, the particulate material being substantially evenly distributed through the metal-based material.

8. An apparatus according to claim 6 wherein the rotatable mixing and shearing and propelling means includes a plurality of upright blade means spaced radially from an axis of rotation, each the blade member being angled relative to a circumferential direction, with a rear edge zone relative to the direction of rotation of each blade member being a radially outermost dimension of each blade member.

9. An apparatus according to claim 8 wherein each blade member forms an angle of about 30 degrees with the circumferential direction.
10. An apparatus according to claim 8 wherein the rear edge zone is spaced from an inner wall surface of the mixing furnace by a distance of between 10 and 30 mm.

11. An apparatus according to claim 7 wherein the delivery means is positioned to deliver the particulate material to a circumferential zone traversed by the upright blade means.

12. An apparatus according to claim 6 wherein the rotatable means includes a central body section adapted to occupy a central zone of the mixing furnace, the central body section having a cylindrical outer surface with a diameter at least 10% of an internal diameter of the mixing furnace.

13. An apparatus according to claim 12 wherein the diameter of the central body section has a diameter of between 15% and 35% of the diameter of the mixing furnace.

14. An apparatus according to claim 6, further including first pump means to move the metal-based material in the thixotropic state from the mixing furnace to the delivery site.

15. An apparatus according to claim 6, wherein the supply means has an exit passage leading from the mixing furnace in a tangential direction whereby flow along the exit passage of the metal-based material is achieved by rotation of the mixing means.

16. An apparatus according to claim 6 wherein the supply means includes an exit passage leading from a central zone of the mixing furnace.

17. An apparatus according to claim 6 wherein the supply means includes an exit passage leading from a side zone of the mixing region.
18. An apparatus according to claim 15, wherein the exit passage is located proximate a mid region of a side zone of the mixing furnace.

19. An apparatus according to claim 6, further including:
   intermediate pump means to move the metal-based material in a thixotropic semi-solid state from the mixing furnace to an intermediate holding furnace, the material being maintained in the intermediate holding furnace in a thixotropic semi-solid state, and
   casting pump means to move the material from the intermediate holding furnace while in a thixotropic semi-solid state to the delivery site.

20. An apparatus according to claim 19 wherein the intermediate and casting pump means include a device selected from the group consisting of a piston, a screw, an electromagnetic pump, and combinations thereof.

21. An apparatus according to claim 6, further including a holding furnace to which the metal-based material is delivered and is held in a molten or semi-molten state prior to being delivered therefrom to the mixing furnace.

22. An apparatus according to claim 6 wherein return means is provided to duct any metal-based material that is not required for casting from the delivery site to the mixing furnace.

23. An apparatus according to claim 6, further including injection means to inject the material from an introduction chamber of a casting machine into the casting machine while in a thixotropic semi-solid state.
MOLTEN ALUMINUM

HOLDING FURNACE

CYCO-TECH AL-MMC MIXER

HIGH PRESSURE DIE CASTING MACHINE

TRIM & INSPECTION

MACHINE & SURFACE ETCH

PACK & SHIP

MELT LOSS

RECYCLE REJECTS

RECYCLE UNUSED MATERIAL, RUNNERS, GATES & BISCUITS

RECYCLE REJECTS

RECYCLE UNUSED MATERIAL, RUNNERS, GATES & BISCUITS

RECYCLE REJECTS

RECYCLE UNUSED MATERIAL

REJECTS & RETURNS

FIG. 1