METHOD FOR PRODUCING FOAMED ALUMINUM PRODUCTS

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ABSTRACT

The present invention is directed to a method for making porous aluminum product and products therefrom and, in particular, a method of rapidly solidifying a liquid metal foam produced by the incorporation of gas forming agents into an aluminum melt. The aluminum melt may be stabilized to support the creation of liquid metal foam by the addition of metal and/or ceramic additives. The decomposition of the gas forming agents and subsequent expansion of the gaseous products is controlled through the use of a reactor, wherein temperature, pressure and transit time can be adjusted to match the decomposition kinetics of the gas forming agent. The invention allows for the economical production of liquid metal foam of uniform cell size that can be continuously cast into sheet, plate and profile sections. Such metal foam products may be used in structural, thermal and acoustic applications.
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BACKGROUND OF THE INVENTION

[0001] The present invention is directed to a method of making porous aluminum products and products therefrom and, in particular, a method of rapidly solidifying a liquid metal foam produced by the incorporation of gas forming agents into an aluminum melt.

BACKGROUND OF THE INVENTION

[0002] Low density porous products offer unique mechanical and physical properties. The high specific strength, structural rigidity and insulating properties of foamed products produced in a polymeric matrix are well known. Such closed cell polymeric foams are used extensively in a wide range of applications, including construction, packaging and transportation.

[0003] While polymeric foams have enjoyed wide market success, foamed metal products have seen only limited applications. Closed cell metallic foams offer many of the attractive attributes of polymeric foam in respect to mechanical and thermal properties. In addition, the inherently higher bulk modulus of metals compared to polymers provides higher specific rigidity. This higher modulus makes metal foams attractive candidates as core materials in laminate panels, where rigidity and resistance to deflection are important performance measures. The fire and smoke resistance of such all metal panels makes them attractive candidates for construction applications. Aluminum foam core sandwich products offer the additional environmental benefit of being recyclable; an issue that has restricted the use of aluminum clad polymer foams.

[0004] While methods of producing foamed metals have been described in the scientific literature and patent literature, all have suffered from problems of either high cost or insufficient structural integrity. Most methods of producing metallic foams fall into two categories: powder metallurgy and casting metallurgy.

[0005] In the powder metallurgy approach, a gas-producing agent (typically TiH₂ or ZrH₂) is mixed with powdered metal (typically aluminum-silicon alloys) and compacted. Such compacts are then further processed through rolling or extrusion prior to being brought to a temperature above the solidus of the alloy. Decomposition of the gas-producing agent occurs at these temperatures within several minutes, resulting in volumetric expansion of the melt and the creation of a porous metal product. While such processing has, to date produced the highest quality metallic foams; the costs of production have been restrictive. The inherent cost the precursors (powdered metal and costly gas producing agents), combined with the multiple processing steps and slow reaction times restrict the use of such foamed metal to only the most exotic and cost insensitive applications.

[0006] The casting metallurgy approach offers the potential of lower manufacturing costs, but efforts to date have suffered from both poor product integrity and high unit costs. Practices have been developed wherein gas producing agents are added directly to the aluminum melts as described in U.S. Pat. Nos. 3,300,296, 3,297,431 and 5,632,319. Other practices have been developed wherein gas is injected into the melt directly and are disclosed in U.S. Pat. Nos. 4,973,358, 5,334,236 and 5,622,542. In both cases, the melts are vigorously agitated to develop a fine distribution of gas bubbles in the liquid metal mass. The melt is then either slowly cooled to retain the foamed mass in the mixing crucible or the froth is extracted from the top of the agitated bulk melt, whereupon it is slowly cooled.

[0007] In all practices using the casting metallurgy approach, some degree of stabilization is required in the metallic melt. A substantial increase in the viscosity of the liquid metal is required to sustain the appropriate rheology to create a stable foam mass in the liquid. The present methods of producing aluminum foam require a high level of such stabilization. This is due to the relatively slow cooling of the liquid foam into a solid mass in all the present practices. All foams are, by nature, meta-stable and therefore prone to both coalescence and decay. To delay such decay, high levels of stabilization are demanded.

[0008] To achieve stabilization, ceramic particulate is added to the melt. These additions are added through either intrinsic or extrinsic mechanisms.

[0009] In the intrinsic method, alloy melts are formulated to induce precipitation of large, intermetallic particles. Typically, high levels of calcium are included in the melt to precipitate calcium aluminate and aluminum-calcium spinel into the melt, which act to increase the melt viscosity. In other intrinsic methods, an aluminum melt is vigorously agitated in air, encouraging the formation of metallic oxides in the melt that act to increase the melt viscosity as described in U.S. Pat. No. 5,632,319 and Aoyagi et al. (Proceedings 5th International Conference on Semi-Solid Processing of Alloys and Composites, A. K. Bhasin, J. J. Moore, K. P. Young and S. Midson (eds.), Colorado School of Mines, 1998, p. 449-455). While cost effective, the present foaming methods require a precursor melt with a very high viscosity, owing to the slow cooling rates employed. In practice this equates to high cost content that, while foamable, produces a final product that is very brittle and has poor general integrity. Additionally, the extended periods of agitation required to produce such a viscous precursor melt detract from the economic attractiveness.

[0010] In the extrinsic method, ceramic particulate is added to the melt directly where needed to promote a melt viscosity that allows for stable, liquid foam to be formed. This extrinsic method has the advantage of allowing selection of ceramic particulate that does not diminish the integrity of the foamed product. The particulate is added into the melt and stirred vigorously to incorporate the ceramic particulate uniformly throughout the melt. This precursor composite melt is then subsequently foamed after the particulate has been sufficiently wetted by the alloy melt. For the particulate to be incorporated, however, and to prevent flocculation, the ceramic must be well wetted, which requires a liquid/ceramic contact angle of less than 90°.

[0011] Experience has shown, however, that it is very difficult to achieve effective wetting of ceramics by liquid aluminum. In the liquid aluminum/oxyide systems, contact angles are typically greater than 100°, i.e. the ceramic is non-wetting. Nominal wetting can be achieved with oxides systems of Al₂O₃ and Al₂O₃ at contact angles of 80° and 75°, respectively, as described in U.S. Pat. No. 5,622,542. The limited wettablity of these ceramics, however, requires
that extensive and aggressive stirring be imposed to incorporate the particulate into the aluminum melt. Additionally, such composite precursor melts have poor bulk properties due to surface reaction layers (similar to the intrinsic products) that limit the ductility of the matrix.

[0012] Similar problems are encountered with the use of non-oxide particulate. As detailed in U.S. Pat. No. 4,973,358, SiC can be used as a particulate addition to enhance viscosity. While SiC can be wetted by liquid aluminum, the melt must be agitated at temperatures over 1400°F for many hours to achieve effective wetting. Moreover, in such precursor composites a deleterious surface layer of Al2C3 develops at the SiC interface, which is highly reactive to moisture, thus limiting the usefulness of the foamed product.

[0013] The difficulty of achieving the appropriate viscosity for production of stable liquid metal foam has, heretofore, been a significant barrier to creating solid metal foam products. Prior methods have required the creation and maintenance of a precursor composite melt of aluminum and ceramic. Such precursor composite melts had to be vigorously agitated for extended periods (hours to days) at temperatures well in excess of the aluminum liquids to fully incorporate the extrinsic particulate, or to precipitate out significant volume fractions of intrinsic particulate. Agitation often resulted in the formation of excessive oxides in the melt. While such oxides actually acted positively to increase the viscosity of the melt, as described in U.S. Pat. No. 5,632,319, the mechanical properties of the aluminum matrix generally diminished, resulting in a brittle and weak product. To limit oxidation, such agitation has often been imposed under conditions of inert atmosphere or vacuum, adding significantly to the expense without decreasing the required agitation time.

[0014] In all previous efforts to create aluminum melts with the appropriate rheology for foaming, the need to maintain large, agitated furnaces of precursor composites has been a technological and financial barrier. This requirement resulted in the economically unattractive practice of batch processing. Additionally, introduction of ceramic particles into industrial furnaces (tilting or otherwise) is generally not considered attractive, as such additions tend to contaminate the furnaces and their linings with such particulate, limiting the further usefulness of the furnaces for general alloy melts. Hence, the use of metallic foams has been minimal due to their high cost of production and/or lack of sufficient structural integrity. A need remains for a method of producing strong foamed aluminum at a reasonable cost.

SUMMARY OF THE INVENTION

[0015] The present invention is a method of making a porous aluminum alloy product comprising the steps of: a) providing an incoming flow of an aluminum alloy melt; b) incorporating small, stable solid particles into the aluminum alloy to increase the melt viscosity and to service as gas bubble nucleation and anchor sites, c) incorporating gas forming agents into said aluminum alloy melt to form an inoculated aluminum alloy melt, d) pumping said inoculated aluminum alloy melt into reactor vessel; e) maintaining said inoculated aluminum alloy melt in said reactor vessel under conditions of pressure, temperature, agitation (mixing) and time so as to control decomposition of the foaming agent; f) releasing said inoculated aluminum alloy melt from said reactor vessel so as to allow expansion of the gas, thereby creating a liquid metal foam; g) rapidly solidifying said liquid metal foam to create a solid foam.

[0016] In a preferred embodiment, metal and/or ceramic additions are added to the aluminum alloy melt to provide stabilization of the liquid metal foam. The metal and/or ceramic additions include a reactive coating such as a nitride, borate, nitrate, phosphate, sulfate, amine or reactive metal such as iron, nickel, copper or silicon. Coatings of alkali metal, alkaline earth, and transition metal oxides, sulfides and halides are also within this invention. A key feature of this invention is the control of bubble size by the customization of the composition and particle size distribution of the foaming agent(s). As an example, Boehmite (AIOH) produces one mole of water for every two moles of Boehmite thermally decomposed. Using the gas law equation of PV=nRT where P is pressure, V is volume, n is the number of moles, R is the universal gas constant, and T is temperature, a calculation can be made to determine the particle size of boehmite to produce one gas bubble with a specific volume or diameter. If gibbsite (Al(OH)3) is used as the gassing agent, three moles of water are produced for every two moles of gibbsite. Thus, the total pore volume produced using the same moles of gibbsite is three times that produced using boehmite.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. 1 is a schematic diagram of a method of making aluminum alloy foam sheet according to the present invention using a twin belt caster that may be operated in a horizontal, tilted or vertical orientation;

[0018] FIG. 2 is a schematic diagram of an embodiment of the invention shown in FIG. 1 using a twin roll caster in place of the belt caster; and

[0019] FIG. 3 is a schematic diagram of another embodiment of the invention including addition of particles for melt stabilization.

DESCRIPTION THE PREFERRED EMBODIMENTS

[0020] For purposes of the description hereinafter, the terms “upper”, “lower”, “right”, “left”, “vertical”, “horizontal”, “top”, “bottom” and derivatives thereof as they are used herein relate to the invention as it is oriented in the drawing figures. However, it is to be understood that the invention may assume various alternative variations and step sequences, except where expressly specified to the contrary. It is also to be understood that the specific devices and processes illustrated in the attached drawings, and described in the following specification, are simply exemplary embodiments of the invention. Hence, specific dimensions and other physical characteristics related to the embodiments disclosed herein are not to be considered as limiting.

[0021] The method of the present invention continuously and rapidly produces foamed aluminum from an aluminum alloy melt by incorporation of gas forming agents into an aluminum alloy melt to produce a liquid foam mass and rapidly solidifying the liquid foam mass to create a continuous sheet or profile of porous metal foam. The liquid foam mass is rapidly solidified in a continuous casting process to
produce an aluminum foam product with a fine and near uniform cell structure. The gas forming agents are added to the melt stream and the inoculated melt is then pumped into a pressurized vessel, or reactor. By pressurizing the melt, the decomposition of the foaming agent and/or the expansion of the gas bubbles formed by said decomposition are suppressed. Upon exiting the pressurized reactor, the inoculated melt rapidly begins to foam. By placing the nozzle of the pressurized reactor at the entrance of the continuous caster, the foamed product can be rapidly solidified. This rapid solidification significantly lowers the level of particulate stabilization required. Additionally, by rapidly quenching the newly formed foam mass, the present invention avoids the problems of coalescence and stratification that has lessened the uniformity of previous aluminum foam structures. The cast product may be coiled continuously or cut with a flying shear, whereupon it can be subsequently used in numerous applications.

[0022] The use of a pressurized reactor allows for a wide selection of foaming agents to be used in the process. In prior efforts to produce aluminum foam, many gas-forming compounds have been rejected due to the intrinsic kinetics of decomposition. In prior efforts, decomposition of gas-forming agents had to be rapid enough to ensure an attractive production rate, and yet slow enough to allow for homogeneous mixing of the agent into the melt prior to decomposition. In practice, these restrictions limited the selection of gas-forming agents to the metal hydrides (such as TiH₂ and ZrH₂) which are too costly to be considered commercially attractive. In the invented process, the use of a reactor allows the pressure, temperature and transit time to be independently controlled. As a result, decomposition of the gas-forming agent and the expansion of the released gases can be suppressed until the reaction is uniformly completed within the melt. The melt can then be released into a lower pressure (such as ambient pressure), allowing for the expansion of the gas products and the formation of liquid metal foam. The liquid metal foam is then rapidly quenched using the methods of continuous casting.

[0023] The rapid quenching allows for a lower level of particulate stabilization than has previously been required in aluminum foam melts. The low level of particulate stabilization of the melt may be accomplished in several ways. The most economically attractive method is to induce foaming in the melt while it is in a semi-solid condition. This may be accomplished by natural cooling of the melt within the trough and/or reactor. In this way the melt can be brought below the liquidus temperature, causing the precipitation of solid phase, which provides sufficient stabilization of the liquid foam mass to prevent coalescence and decay prior to its rapid solidification.

[0024] As the temperature difference between the onset of solidification and its completion is determined by alloy composition, alloys with a wide freezing range are preferred. Alloy compositions may be adjusted to widen this freezing range and induce the precipitation of desirable solid phases within the melt.

[0025] Additional stabilization of the melt may be provided by the direct injection of metal and/or ceramic additives along with or prior to incorporation of gas forming agent. Alternatively, the stabilizing particulate may be the foaming agent itself. Particularly attractive forms of melt stabilizing additives are the highly oxidized by-products of the aluminum melting and recycling path. Such by-product materials include dross collected from prior cast house operations as well as fine particulate matter (consisting primarily of aluminum metal powder and aluminum oxides) collected from the recycling flow path. To enhance the wettability and hence the case with which such additions may be incorporated, the additives may be selected such that they are either themselves reactive to the melt or bear a reactive coating which makes the particles wettable by the melt. The rapid quenching allows for a lower level of particulate stabilization than has previously been required in aluminum foam melts.

[0026] The method of creating liquid foam mass and subsequent processing equipment can be used in conjunction with conventional cast house practice at conventional cast house facilities. This inventive process, therefore, provides a method of producing aluminum foam products without the need for a dedicated melting facility. As such, the apparatus is particularly well suited for use at aluminum recycling facilities. The method may be effective with a wide range of aluminum melt compositions; hence, the present invention is particularly well suited for feedstock containing low value aluminum scrap. Such mixed scrap streams conventionally have low market value due to high levels of undesirable contaminants, such as iron, silicon, zinc, lithium and other metals, as well as non-metallic inclusions. Mixed alloy scrap generally cannot be recycled for use in structural applications and is traditionally restricted to very low value applications, such as de-oxidizing agents in the steel industry. The indifference of the present process to alloy purity and inclusion levels, as well as the compatibility with existing cast house furnaces and melt handling systems, make the process of the present invention uniquely well suited for use in creating structural products from low value scrap streams at low capital expenditures.

[0027] The method and apparatus of the present invention provide for continuous production of foamed aluminum products that can be produced directly from furnaces and holders of aluminum and aluminum alloys and does not require the maintenance of large aluminum/ceramic composite melt precursors. The present invention may utilize low value aluminum scrap streams as feedstock material.

[0028] The present invention is particularly suited for making thin, low density sheet product with a closed cell metallic structure having properties of low density, high specific stiffness and high specific strength. The foamed aluminum made according to the present invention may be used as a lightweight core material for the construction of face sheeted products, such as panels.

[0029] The method and apparatus of the present invention may be used to produce thin, closed cell foam of an aluminum alloy matrix.

[0030] As shown in FIG. 1, one embodiment of the invention includes a foam manufacturing system 1 for manufacturing metal foam products from molten metal. Manufacturing system 1 has tilting furnace 4 for providing an aluminum melt 6 through trough 8 to mixer unit 9.

[0031] Gas forming agent 7 flows into mixer unit 9 to form an inoculated melt. Gas forming agent 7 may include stabilizing additives. The inoculated melt is pumped using a
known molten metal pump 16. Either a centrifugal or reciprocating pump are commonly used to pump molten metals.

[0032] Molten metal pump 16 pumps the inoculated metal to pressurized vessel (also referred to as a reactor) 11. The volume, length and pressure of reactor 11 are designed according to the reaction kinetics of the foaming agent.

[0033] Outlet 22 of reactor 11 is positioned to deliver the reacted melt to the nip of continuous twin belt caster 24. Outlet 22 is sufficiently restrictive to maintain the pressure within reactor 11. The exact size and shape of outlet 22 is governed by the size and shape of roll 29 as well as by its motion. Alternatives to roll 29 include a gate or auger (both not shown). The twin belt caster may be operated in a horizontal orientation of the belts as shown in FIG. 1 or in a tilted or vertical orientation.

[0034] In operation, melt 6 flows into mixer unit 9 wherein the foaming agent is added, along with, and in one embodiment, the stabilizing metal and/or ceramic additive. The inoculated melt, which now may be partially stabilized, is pumped into reactor 11 and maintained in said reactor at a pressure and temperature so as to control the decomposition of the foaming agent and regulate the expansion of the gas bubbles. Outlet 22 restricts the release of the melt so as to maintain the pressure within the reactor.

[0035] The belt casting embodiment of the invention as shown in FIG. 1 is particularly well suited for use in the present invention because twin belt casting does not impose substantial compression or shear strain on the solidifying foam mass which could otherwise induce buckling and waviness into the cell walls of the foam product. The molten metal foam is solidified into a solid foam sheet 28 in the belt caster 24 and may be wound into a coil 30. Alternatively, sheet 28 may be cut to length with a flying shear, flying saw or the like (not shown).

[0036] The pressure in reactor 11 is controlled by metal pump 16, the dimensions of the outlet 22, the actions of metering gate or roll 29, and the speed of the caster 24 which conveys the solidifying metal foam. The gas content of the liquid foam can be adjusted through these process variables, as well as by the selection of the gas forming agent. By placing outlet 22 close to caster 24, the viscosity of the melt may be lower than in previous systems for producing aluminum foam and still avoid the issues of coalescence and stratification within foamed sheet 28.

[0037] Other methods of continuous casting may be employed in practicing the invention. Such alternatives include melt drag casting, planar flow casting, twin roll casting, single roll casting, single belt casting, and block casting (wherein solidification is accomplished between two articulated chill block assemblies).

[0038] In FIG. 2, a system 2 similar to the system 1 is shown but which uses roll casting. In this embodiment, a twin roll caster 25 is placed adjacent to outlet 22 of reactor 11 and a roll 26 is included to aid in handling of sheet 28.

[0039] FIG. 3 depicts another embodiment of the invention in which metal and/or ceramic additives are injected into the melt using a separate mixer unit 32 from source 33 to increase melt viscosity without maintaining a precursor melt within a crucible. The system of FIG. 3 is similar to the system of FIG. 1 and further includes a source 33 of particles. Other arrangements besides the particle source 33 may be used to deliver particles to the melt stream entering reactor 11. The system of FIG. 3 may also employ a roll caster or other continuous caster in place of belt caster 24.

[0040] The metal and/or ceramic additions which are incorporated into the melt at either at the mixer unit 9 or 32 (should two mixing units be used) may either themselves to the melt or bear a reactive coating, which makes the particles wettable by the melt 6. A coating of reactive wetting agents on the particles creates an in-situ composite when brought in contact with the liquid aluminum. This reactive wetting is facilitated by the mixing action of mixing units 9 or 32. Such pretreated additives ensure rapid and effective wetting of the particles by the aluminum melt 6.

[0041] In the present invention, a reactive coating may be applied to the additives prior to their incorporation into the melt to facilitate reactive wetting and contact angles of less than 90°. A preferred reactive coating is a nitride composition such as MgN2. The composition of the ceramic particulate can be varied, though low cost particulate, such as metallurgical grade Al2O3 are preferred due to their availability and compatibility with standard recycling techniques. Other suitable coatings include borates, nitrates, phosphates, sulfates, amines and reactive metals such as iron, nickel, copper and silicon.

[0042] The rapid quenching (immediate solidification of foam) allows for a lower level of particulate stabilization than has previously been required in aluminum foam melts. Additionally, by rapidly quenching the newly formed foam mass, the present invention avoids the problems of coalescence and stratification that has lessened the uniformity of previous aluminum foam structures.

[0043] Preferably, foam sheet 28 is produced at a gauge of about 0.01 inch to about 0.375 inch. This range of thickness assures both rapid heat extractions for high productivity levels and sufficient compliancy of the final product, such that cooling can be achieved without excessive strain on the outer surface of the initial wraps of the coil 30. Alternatively, thicker gauges may be produced by using a flying shear or the like down line from the caster unit to produce foam plate products with gauges from about 0.25 inch up to at least 1.0 inch.

[0044] In another embodiment of the invention (not shown), a sheet of another aluminum alloy can be laminated to the foam sheet 28 by feeding a coil of another alloy to the caster and simultaneously casting the foam and laminating the additional sheet thereto. A sheet of another alloy may be bonded to one or both side of the foam sheet 28.

[0045] Low cost, scrap aluminum alloy may be used as a raw material for the foam produced according to the present invention. The sheet or plate products produced thereby may have end uses that heretofore have not employed aluminum. Examples of end products made from the foam produced according to the present invention include packaging materials (as a substitute for corrugated cardboard), automotive structures (e.g., vehicle panels), fireproof building products (e.g., doors, roofing materials), acoustic (sound deadening) panels, thermal insulating materials, and construction materials (as a substitute for plywood). Aluminum foam is significantly stronger than any of these conventional products.
It will be readily appreciated by those skilled in the art that modifications may be made to the invention without departing from the concepts disclosed in the foregoing description. Accordingly, the particular embodiments described in detail herein are illustrative only and are not limiting to the scope of the invention.

What is claimed is:
1. A method of making a porous aluminum alloy product comprising the steps of:
   a. providing an incoming flow of an aluminum alloy melt;
   b. incorporating small, stable solid particles into said aluminum alloy to increase the melt viscosity and to service as gas bubble nucleation and anchor sites;
   c. incorporating gas forming agents into said aluminum alloy melt to form an inoculated aluminum alloy melt;
   d. transferring said inoculated aluminum alloy melt into a reactor vessel;
   e. maintaining said inoculated aluminum alloy melt in said reactor vessel under conditions of pressure, temperature and time so as to initiate decomposition of the foaming agent;
   f. releasing said inoculated aluminum alloy melt from said reactor vessel so as to allow expansion of the gas, thereby creating a liquid metal foam;
   g. rapidly solidifying said liquid metal foam to create a solid foam.

2. The method according to claim 1 wherein metal and/or ceramic additions are added to said aluminum alloy melt to provide stabilization of the liquid metal foam.

3. The method according to claim 2 wherein said additions are added prior to incorporating said gas-forming agents.

4. The method according to claim 2 wherein said additions are added mixed with said gas forming agents prior to step b.

5. The method according to claim 2 wherein said additions are added after step b.

6. The method according to claim 1 wherein said liquid metal foam is rapidly solidified to create a continuously cast shaped profile product.

7. The method according to claim 1 wherein said liquid metal foam is rapidly solidified to create a continuously cast sheet or plate product.

8. The method according to claim 1 wherein said liquid metal foam is solidified between moving twin belts.

9. The method according to claim 1 wherein said liquid metal foam is solidified between moving twin rolls.

10. The method according to claim 1 wherein said liquid metal foam is solidified onto a single roll.

11. The method according to claim 1 wherein a sheet of another aluminum alloy is laminated to one or both sides of the foam sheet by feeding sheet to the caster and simultaneously casting the foam and laminating the additional sheet or sheets thereto.

12. A method according to claim 2 wherein said metal and/or ceramic additions are reactive to said aluminum melt such that the additions are wetted by the alloy melt.

13. A method according to claim 2 wherein said metal and/or ceramic additions are treated to form a reactive coating such that the additions are wetted by the alloy melt.

14. The method according to claim 13 wherein the metal and/or ceramic additions include a reactive coating such as a nitride, borate, nitrate, phosphate, sulfate, amine or reactive metal such as iron, nickel, copper or silicon.

15. The method according to claim 1 wherein said nitride is Mg₃N₂.

16. The method according to claim 2 wherein the metal and/or ceramic additions are the highly oxidized by-products of the aluminum melting and recycling path.

17. The method according to claim 1 wherein said transferring is accomplished by gravity feed.

18. The method according to claim 1 wherein said transferring is accomplished by means of a pump.

19. The method according to claim 13 wherein the metal and/or ceramic additions include a reactive coating such as alkali metal, alkaline earth, and transition metal oxides, sulfides and halides.

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