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TRANSFORMABLE AND RECYCLABLE SEMI-SOLID METAL PROCESSING

FIELD OF THE INVENTION

5 The present invention relates to a method for treating an alloy for Semi-Solid Metal Processing (SSMP). It also relates to a method and system for Semi-Solid Metal Processing or fabricating metal components.

BACKGROUND OF THE INVENTION

10 Metal components or parts are conventionally manufactured by casting, forging and/or machining processes. Casting processes such as sand casting, die-casting or the like pour or force a molten metal into a mold, and cool down the molten metal in the mold to its solid form to obtain components or parts. In a
15 conventional forging process, metals are first heated to a temperature below its solidus temperature and plastically deformed by a press machine to form a component or part with a desired shape and dimension.

20 While the casting process requires heating the metal material above its liquidus temperature and the forging process requires heating the metal material below its solidus temperature, another process called "semi-solid metal processing" (SSMP) was developed in 1970's by Flemings et al as disclosed, for example in US patent 3,948,650, which fabricates metal components or parts in a temperature range between the liquidus and solidus temperature of the metal
25 material, i.e. the metal material is in a state of a mixture of liquid and solid materials during the process. With many advantages such as the components or parts formed thereof may achieve complex geometry, higher strength, weldable and heat treatable, and improved mold worklife, the SSMP process has been widely used in industrial applications to manufacture metal components and parts.

30 To produce metal components or parts using SSMP, one important step is to modify the dendritic microstructure which would normally be produced on

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conventionally-solidified metal material. Such dendritic microstructures have been avoided by preparing a material slurry of a solid-liquid composition composed of solid, relatively fine and non-dendritic particles in a liquid matrix (hereinafter referred to as a semi-solid material).

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A variety of researches has been carried out into controlling microstructures of solidified metals and alloys. One example is disclosed in US Patent 4,450,893 to Winter et al, which relates to apparatus and method for continuously or semi-continuously slurry casting thixotropic metal slurries. The method comprises supplying a charge of metal which is at least 35% liquid and utilizing electromagnetic forces to agitate the slurry, producing shear rates sufficient to prevent interconnected networks of branched dendrites from developing.

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While the above electromagnetic agitation may be able to break up the dendritic microstructure hence convert the same into globular microstructure as required for SSMP processing, it remains a relatively higher manufacturing cost as because of, for example, the equipment and its handling costs for a electromagnetic device and the agitation process. This method also has certain limitations to the type of metal materials as due to the nature of the electromagnetic agitation.

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Another problem of this electromagnetic agitation process is that when a component manufacturer purchases SSMP-producible alloy from an SSMP-material vendor for fabricating components, the scraps generated during the process (i.e. in a die-casting process), when attempted to send back to the melting process to recycle, its globular-like microstructure will be converted back to dendritic microstructure. As such, the scraps of the metal material are not able to be directly re-used or recycled as semi-solid material by the component manufacturer if it has no electromagnetic agitation facilities.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a method for the preparation of semi-solid material for the manufacturing of the metal components or parts. According to the present invention, a method for heat-treating an alloy to modify its dendritic microstructure for improved semi-solid metal processability is provided, which is able to effectively convert the normally dendritic-microstructured metal material into a globular and/or equiaxed-microstructure, which is suitable for SSMP processing without the need of an electromagnetic agitation process. The method according to the present invention is applicable to common die-casting materials such as Aluminum (Al) or Magnesium (Mg) alloys and in addition, it is also suitable for direct recycling the scraps of the common die-casting materials.

In accordance with a first aspect of the present invention, there is provided a method for heat treating an alloy to modify its dendritic microstructure for improved semi-solid metal processability, the method comprises heating the alloy to a first temperature above its liquidus temperature to form a molten alloy, and adding a refiner into the molten alloy. The molten alloy is then cooled down and solidified to form an alloy slug with a globular and/or equiaxed microstructure for further SSMP processing, to produce metal components or parts.

Preferably, the first temperature is controlled to not more than about 50 °C above the liquidus temperature of the alloy and more preferably, the first temperature is controlled at about 40-45 °C above the liquidus temperature of the alloy.

In one embodiment, the alloy is solidified from a near-liquidus temperature of not more than about 50 °C above the liquidus temperature of the alloy.

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Preferably, the refiner comprises at least one element selected from Na, Ti, B, Ce, Zr and Ca. More preferably, the refiner comprises at least two elements selected from Na, Ti, B, Ce, Zr and Ca.

5 Preferably, the contents of the refiner added in the molten alloy is about 0.0001% to about 0.5% in weight.

Subsequent steps are provided, which may be integrated into the above method as a whole SSMP process, or be done separately. These steps comprise
10 re-heating the alloy slug to a temperature between the liquidus temperature and the solidus temperature of the alloy to form a softened billet and further, the softened billet maybe cast-formed or forged to form the final components or parts.

Preferably, the method further comprises supplying a scrap generated
15 during forming of the component to the melting of the alloy to recycle the scrap.

In accordance with a second aspect of the present invention, there is provided an integrated system for fabricating metal components. The system comprises a heating module, a refining module, and a cooling module. The
20 heating module heats up a metal material to a temperature above its liquidus temperature to melt the metal material. The refining system receives the molten metal material from the heating module and adds a refiner into the molten metal. Thereafter, the metal material with the refiner added is solidified in the solidifying module to form a metal slug with a globular and/or equiaxed microstructure.

25 The heating module heats up the metal material to a temperature of not more than about 50 °C above its liquidus temperature to melt the metal material.

In one embodiment, the system further comprises a re-heating module and
30 a forming module. The re-heating module receives the metal slug from the solidifying module and heats up the metal slug to a temperature between its solidus temperature and its liquidus temperature to form a softened billet. The

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forming module receives the billet from the re-heating module and forms the metal component. The metal component may be formed by casting or forging or other suitable process.

5 Preferably, the system further comprises a recycling module for supplying a scrap material, either generated during the forming process or supplied from a separate source, to the heating module for recycling purpose.

10 Preferably, the metal slug is fabricated by a method according to the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

15 Fig. 1A is a flowchart showing the method according to one embodiment of the present invention.

Fig. 1B is a flowchart showing the subsequent steps of forming components or parts following that shown in Fig. 1A according to one embodiment of the present invention.

20 Figs. 2A and 2B are enlarged schematic views showing the microstructures of the alloy produced according to one embodiment of the invention;

25 Fig. 3A is a microscopic photograph showing the globular-like microstructure of an LM5 alloy slug formed according to the present invention;

Fig. 3B is a microscopic photograph showing the dendritic microstructure of a prior art die casting alloy;

30 Fig. 3C is a microscopic photograph showing the globular-like microstructure of an A6082 alloy slug formed by using prior art electromagnetic agitation process;

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Fig. 4 is a chart showing the experimental results of mechanical properties of specimen formed according to the conventional electromagnetic agitation and the present invention;

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Fig. 5A is a fractograph showing microstructure of an A6082 alloy produced by using the conventional electromagnetic agitation process;

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Fig. 5B is a fractograph showing microstructure of an LM5 alloy produced according to the present invention.

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Fig. 6 is a schematic drawing showing a system for fabricating metal components by casting or forging according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

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A method 100 for heat treating an alloy to modify its dendritic microstructure for improved semi-solid metal processing (SSMP) according to one embodiment of the present invention may be illustrated in Fig. 1A. In a first block 120, a die-casting alloy which has initially a normal dendritic microstructure, such as an LM5 alloy, is heated up to a temperature of not more than about 50°C, such as about 40°C – 50 °C above its liquidus temperature. The alloy is now molten.

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It is believed that when the dendritic microstructured alloy is molten, there exists short-range ordered near-solid structures in the molten alloy. When the alloy is heated to a relatively higher temperature such as 100°C above its liquidus line, as the case in the conventional method, for example, these short-range ordered near-solid structures will be greatly reduced or eliminated.

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By controlling the melting temperature to not more than 50 °C above its liquidus temperature, it is believed that the short-range ordered near-solid structures are maintained in the molten alloy.

5 In a next block 130, a refiner made of one or more of Na, Ti, B, Ce, Zr and Ca and/or combinations thereof, with a content of about 0.0001% in weight to about 0.5% in weight, is added into the molten alloy LM5.

10 In a next block 140, the molten alloy with the refiner added is cooled down, under either normal gravity or high consolidation pressure by use of an injection system, to its solid phase and form an SSMP-processable alloy slug.

15 The cooling process may be controlled by using water-cooling or air-cooling. As an example, water pipes with a diameter of 10 ~ 15 mm is used to surround a molten alloy container. Water flows with a flow rate of about 2 – 5 litres/min. within the pipe to achieve the cooling. Alternatively, air-cooling method may be used, which uses air pipes of 10 ~ 15 mm in diameter and 3 – 8 bar of air pressure for achieve the air-cooling.

20 It is believed that by virtue of the refiner added in the molten alloy which contains short-range ordered near-solid structures, the formation of the dendritic microstructure is prevented in the solidified alloy and instead, the alloy is obtained with globular and/or equiaxed microstructure is obtained, which is suitable for SSMP processing.

25 According to one embodiment of the present invention shown in Fig. 1B, in a first block 150, an alloy slug obtained according to a method as shown in Fig. 1A is re-heated to a temperature between the liquidus and the solidus temperature of the alloy to form a softened billet, which preferably contains a liquid fraction ranging from about 40% to about 60%. In a next block 160, the softened billet
30 may be processed to form desired mechanical components or part by, for example, casting or forging.

As shown in Fig. 2A, when heated up to a temperature above the liquidus temperature as illustrated in the block 110 of Fig. 1A, the alloy 200 contains near-solid clusters 210. With adding-in of the refiner, the large sized near-solid clusters 210 in the molten alloy 200 are converted to many local-area near-solid clusters 220, as shown in Fig. 2B. By virtue of the heterogeneous nucleation and the refinement, the alloy 200 eventually have a much finer globular and/or equiaxed structure, with near-homogeneous nucleation 230 after a gravity rapid cooling or a pressure rapid cooling.

Fig. 3A shows that, an LM5 alloy processed according to the present invention possesses a globular-like microstructure, which is significantly different from the dendritic microstructure of a prior art die-casting alloy, as shown in Fig. 3B. To the contrary, the microstructure shown in Fig. 3A is substantially similar to an A6082 alloy produced by the conventional electromagnetic agitation process, as shown in Fig. 3C. These results show that an alloy prepared according to the present invention has a globular-like microstructure which is similar to that prepared by conventional electromagnetic agitation technology, therefore it is suitable for subsequent manufacturing steps to produce mechanical components or parts based on the SSMP technology.

In an experimental test result shown in Fig. 4, there further shows that the strength of the LM5 alloy produced according to the present invention possesses a 224Mpa strength, a 22.3% elongation and a 70 HRF hardness, which are higher or at least comparable to an A6082 alloy produced by the conventional electromagnetic agitation process, which has an 175 MPa strength, 25.4% elongation and 64 HRF hardness, respectively.

The fractographs of both an A6082 alloy and an LM5 alloy produced by the conventional electromagnetic vibration and the present invention, respectively can also be seen in Figs. 5A and 5B, which show the presence of dimples on the

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fracture surface of LM5 alloy is similar to that of the A6082 alloy, which indicates the ductile behavior of the alloy.

5 As shown in Fig. 6, a system 600 for forming metal components according to one embodiment of the present invention comprises a heating module, such as a furnace 610, a refining module 620, a solidifying 630, a re-heating module 640, a forming module, such as a die-casting or a forging machine 650 and a recycling module 660. The furnace 610 receives the raw metal material, which has a normal dendritic microstructure, and heats it up above its liquidus temperature to melt the metal material. The refining module 620 receives the molten metal from the furnace 610 and adds a refiner therein. The solidifying module 630 receives and cooled down the refined metal material from the refining module 620 to form a solidified metal slug with a globular and/or equiaxed microstructure.

15 The re-heating module 640 receives the metal slug from the solidifying module 630 and heats it up to its semi-solid state (i.e. a temperature between the solidus and liquidus temperature) to form a softened billet. The die-casting machine 650 receives the softened billet from the re-heating module 640 and produce final components or parts by die-casting.

20 The scraps generated by the die-casting machine 650 may be collected by the recycling module 660 and supplied back to the furnace 610 for recycling purpose.

25 A controlling module 670 may be provided to control and coordinate the operations of the furnace 610, the refining module 620, the cooling module 630, the re-heating module 640, the die-casting machine 650 and the recycling module 660 to regulate and optimize the operation of the system.

CLAIMS

1. A method for treating an alloy to modify its dendritic microstructure for improved semi-solid metal processability, the method comprising:
5 heating the alloy to a temperature above its liquidus temperature to form a molten alloy whilst maintaining the short-range ordered near-solid structures;
adding a refiner to the molten alloy;
solidifying the molten alloy with the refiner by rapid-cooling to produce
10 an alloy with globular-like microstructure.
2. The method as recited in claim 1, further comprising controlling the temperature to maintain short-range ordered near-solid structures in the molten alloy.
- 15 3. The method as recited in claim 2, wherein the temperature is no more than about 50°C above its liquidus temperature.
4. The method as recited in claim 3, wherein the temperature is about 40-
20 45°C above its liquidus temperature.
5. The method as recited in claim 1, wherein the alloy is solidified from a near liquidus temperature of not more than 50°C above its liquidus temperature.
- 25 6. The method as recited in claim 1, wherein the rapid-cooling is effected by gravity rapid-cooling.
7. The method as recited in claim 1, wherein the rapid-cooling is effected by pressure rapid-cooling.
- 30 8. The method as recited in claim 1, wherein the refiner comprises at least one element selected from Na, Ti, B, Ce, Zr and Ca.

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9. The method as recited in claim 8, wherein the refiner comprises at least two elements selected from Na, Ti, B, Ce, Zr and Ca.

5 10. The method as recited in claim 1, wherein the contents of the refiner added in the molten alloy is about 0.0001% to about 0.5% in weight.

11. A method of fabricating a metal component, the method comprising
providing an alloy prepared according to claim 1;
10 re-heating the alloy to a temperature between its solidus and liquidus temperature to form a softened billet;
forming the component by using the softened billet.

12. The method as recited in claim 11, further comprising supplying a scrap
15 generated during forming of the component to the heating of the alloy to recycle the scrap.

13. A system for fabricating metal components, the system comprising:
a heating module for heating up the metal material above its liquidus
20 temperature to melt the metal material;
a refining module for receiving the molten metal material from the heating module and adding in a refiner into the molten metal material;
a solidifying module for receiving the refined molten metal material from
25 the refining module and solidifying the molten metal material by rapid-cooling to form a metal slug;
wherein the metal are heated in the heating module to a temperature of about 50°C above its liquidus temperature.

30 14. The system as recited in claim 13, further comprising:
a re-heating module for receiving the metal slug from the cooling module and heating up the metal slug to a temperature between its

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solidus temperature and its liquidus temperature to form a softened billet;

a forming module for receiving the billet from the re-heating module for processing the billet to form the metal component.

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15. The system as recited in claim 14, further comprising a recycling module for supplying a scrap material back to the heating module.

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16. The system as recited in claim 13, wherein the metal components are fabricated according to a method as recited in claim 1.