In a process for producing die-cast parts made of an aluminum alloy, the aluminum alloy is exposed to high shearing forces in a mixing and kneading machine, is removed as partially solid aluminum alloy with a predefined solids content, is transferred into a filling chamber of a die-casting machine and is introduced into a casting mold using a piston, wherein a solids content of the aluminum alloy in a working space of the mixing and kneading machine is set to a predefined solids content by cooling and heating the working space in a targeted manner.
PROCESS FOR PRODUCING DIE-CAST PARTS

[0001] The invention relates to a process for producing die-cast parts made of an aluminum alloy.

[0002] Die-cast parts made of aluminum alloys are being used ever more frequently, inter alia, in the automotive industry for reasons of an increasing demand for weight reduction. For casting technology reasons, it is generally the case that a cast part wall thickness of about 2 mm cannot be undershot, for example in the case of nodes for space frame structures, with conventional die-casting processes. The filling of the die-casting mold with partially solid metal melts by using thixocasting or rheocasting leads to better filling of the mold and, as a result, to a possible further reduction in the cast part wall thickness to about 1 mm. As the wall thickness decreases, however, the reduced force-absorption capability increasingly becomes a limiting factor. This disadvantage by itself could be countered by the addition of nanoparticles to an aluminum alloy matrix. However, there is a lack of suitable processes for cost-effectively producing aluminum alloys reinforced with nanoscale particles and for the preparation thereof to form partially solid metal melts for die casting.

[0003] The invention is based on the object of providing a process of the type mentioned in the introduction, with which process a partially solid aluminum alloy melt can be provided continuously in a cost-effective manner and further processed to form die-cast parts. It is a further object of the invention to provide a process for producing die-cast parts which are reinforced with nanoparticles and are made of an aluminum alloy, with which process a partially solid aluminum alloy melt can be provided continuously in a cost-effective manner under the action of shearing forces typical of the process with a high fine dispersion of nanoparticles and further processed to form die-cast parts.

[0004] The first object is achieved according to the invention in that the aluminum alloy is exposed to high shearing forces in a mixing and kneading machine, having a housing with a working space, which is surrounded by an inner housing sleeve, and a worm shaft, which rotates about a longitudinal axis and moves to and fro translationally in the longitudinal axis in the inner housing sleeve and is provided with kneading blades, and with kneading bolts, which are fastened to the inner housing sleeve and protrude into the working space, wherein liquid aluminum alloy and nanoparticles are fed to the working space at one end of the housing and, at the other end of the housing, are removed from the working space as a partially solid metal strand. The continuously emerging, partially solid metal strand is split into partially solid metal portions and the partially solid metal portions are transferred into the filling chamber of the die-casting machine.

[0005] The second object is achieved according to the invention in that nanoparticles are mixed with the aluminum alloy and finely dispersed in the aluminum alloy by high shearing forces in a mixing and kneading machine, having a housing with a working space, which is surrounded by an inner housing sleeve, and a worm shaft, which rotates about a longitudinal axis and moves to and fro translationally in the longitudinal axis in the inner housing sleeve and is provided with kneading blades, and with kneading bolts, which are fastened to the inner housing sleeve and protrude into the working space, wherein liquid aluminum alloy and nanoparticles are fed to the working space at one end of the housing and, at the other end of the housing, are removed from the working space as partially solid aluminum alloy with a predefined solids content and with nanoparticles finely dispersed in the aluminum alloy, are transferred into a filling chamber of a die-casting machine and are introduced into a casting mold by means of a piston, wherein the solids content of the aluminum alloy in the working space is set to the predefined solids content by cooling and heating the working space in a targeted manner. Here, in addition to the comminution of dendritic branches which form and the resultant higher ductility, the high shearing forces present in the kneading process in the partially solidified phase state finely disperse the nanoparticles, which is required for the strength-increasing effect thereof.

[0006] It is expedient that the inner housing sleeve is surrounded by an outer housing sleeve such that an intermediate space preferably in the form of a hollow cylinder is formed, and cold and/or hot gases are conducted through the intermediate space for cooling and heating the working space. Air, preferably compressed air, is preferably conducted through the intermediate space for cooling, and hot gases, preferably combustion gases, are preferably conducted through the intermediate space for heating.

[0007] The gases are preferably conducted through the intermediate space in countercurrent to the direction in which the aluminum alloy is transported.

[0008] The solids content of the aluminum alloy is preferably set to 40 to 80%, in particular to more than 50%.

[0009] In a preferred embodiment of the process according to the invention, the partially solid aluminum alloy is removed from the working space as a partially solid metal strand. The continuously emerging, partially solid metal strand is split into partially solid metal portions and the partially solid metal portions are transferred into the filling chamber of the die-casting machine.

[0010] The content of the nanoparticles in the alloy is preferably between about 0.1 and 10% by weight. Suitable, cost-effective nanoparticles consist preferably of fumed silica, such as e.g. Aerosil®. However, it is also possible to use other nanoparticles, such as e.g. the known carbon nanotubes (CNT) and also further, nanoscale particles which are produced, for example, by the known Aerosil® process and are made of metal and semimetal oxides, such as e.g. aluminum oxide (Al₂O₃), titanium dioxide (TiO₂), zirconium oxide (ZrO₂), antimony(III) oxide, chromium(III) oxide, iron(III) oxide, germanium(IV) oxide, vanadium(V) oxide or tungsten(VI) oxide.

[0011] Further advantages, features and details of the invention will become apparent from the following description of preferred exemplary embodiments and with reference to the drawing, which serves merely for elucidation and is not to be interpreted as having a limiting effect. Schematically, in the drawing.

[0012] FIG. 1 shows a longitudinal section through a die-casting machine with an upstream mixing and kneading machine;
FIG. 2 shows a longitudinal section through part of a mixing and kneading machine;

FIG. 3 shows a cross section through the mixing and kneading machine shown in FIG. 1;

FIG. 4 shows characteristic shearing and stretching flow fields in a product mass, triggered by a kneading blade moving past a kneading bolt;

FIG. 5 shows the continuous production of partially solid starting material for die casting with an arrangement according to FIG. 1.

A plant, shown in FIG. 1, for die casting die-cast parts which are optionally reinforced with nanoparticles and are made of an aluminum alloy has a die-casting machine 10 and a mixing and kneading machine 30 upstream of the die-casting machine 10.

The die-casting machine 10, which is shown only in part in the drawing, is a commercially available machine for conventionally die casting aluminum alloys and has, inter alia, a filling chamber 12, which is connected to a stationary side 18 of a casting mold, with an opening 16 for receiving the metal which is to be ejected from the filling chamber 12 and introduced into a mold cavity 14 of the casting mold by means of a piston 20.

The mixing and kneading machine 30 is shown in detail in FIGS. 2 and 3. The basic design of such a mixing and kneading machine is known, for example, from CI1-A-2758 2757. The mixing and kneading machine 30 has a housing 31 with a working space 34, which is surrounded by an inner housing sleeve 32 and in which there is arranged a worm shaft 36, which rotates about a longitudinal axis X and moves to and fro translationally in the longitudinal axis X in the inner housing sleeve 32. The worm shaft 36 is interrupted in the circumferential direction such that individual kneading blades 38 are formed. Axial through openings 40 are thereby formed between the individual kneading blades 38. Kneading bolts 42 protrude from the inner side of the inner housing sleeve 32 into the working space 34. The kneading bolts 42 on the housing side engage into the axial through openings 40 of the kneading blades 38 arranged on the main or worm shaft 36. A drive shaft 44 arranged concentrically to the worm shaft 36 is guided out of the inner housing sleeve 32 at the end and is connected to a drive unit (not shown in the drawing) for executing a rotational movement of the worm shaft 36. A device interacting with the worm shaft 36 for executing the translational movement of the worm shaft 36 is likewise not shown in the drawing.

The cylindrical inner housing sleeve 32 of the mixing and kneading machine 30, which delimits the working space 34, is surrounded by a cylindrical outer housing sleeve 46. The inner housing sleeve 32 and the outer housing sleeve 46 form a dual sleeve and thereby enclose an intermediate space 48 in the form of a hollow cylinder.

An introduction opening 50 for feeding liquid aluminum alloy and optionally nanoparticles into the working space 34 is provided at that end of the housing 31 which is close to the drive side of the worm shaft 36. Although only one introduction opening 50 is shown in the drawing, two separate introduction openings for the aluminum alloy and for the nanoparticles can be provided. In principle, it is also possible to admix the nanoparticles with the liquid aluminum alloy even before the metal is introduced into the kneading and mixing machine 30. An outlet opening 52 for removing partially solid aluminum alloy optionally with nanoparticles dispersed therein is provided at that end of the inner housing sleeve 32 which is remote from the drive side of the worm shaft 36.

Inlet openings 54, 56 for introducing cold or hot gases into the intermediate space 48 are provided in the outer housing sleeve 46 at that end of the housing 31 which is remote from the drive side of the worm shaft 36. Correspondingly, outlet openings 58, 60 for the discharge of the gases from the intermediate space 48 are provided at that end of the housing 31 which is close to the drive side of the worm shaft 36. In order to ensure a maximum throughflow of gas, which is distributed uniformly over the circumference of the inner housing sleeve 32, from the inlet openings 54, 56 to the outlet openings 58, 60, and thus a uniform discharge of heat from the working space 34 or a uniform introduction of heat into the working space 34, the inlet and outlet openings 54, 56 and 58, 60, respectively, are according to FIG. 3 arranged distributed uniformly about the circumference of the outer housing sleeve 46.

FIG. 4 shows, in a schematic illustration, characteristic shearing and stretching flow fields in a product mass P as triggered by a kneading blade 38 moving past a kneading bolt 42 in the case of a mixing and kneading machine 30 formed according to the prior art. The direction in which the kneading blade 38 rotates is indicated schematically by a curved arrow A, whereas the translational movement of the kneading blade 38 is indicated by a double-headed arrow B. The rotational movement of the kneading blade 38 means that its tip splits the product mass P, as indicated by arrows C, D. There is a gap 41, the width of which varies depending on the rotation and translational movement of the worm shaft 36, between the kneading bolt 42 and the main face 39 of the kneading blade 38, which faces toward the kneading bolt 42, and the kneading blade 38 moving past the latter. A shearing process is brought about in the product mass P in this gap 41, as indicated by arrow E. The product mass P expands and reorients itself both upstream and downstream of the kneading bolt 42, as indicated by rotation arrows F, G. As already mentioned in the introduction, there is a maximum convergence of the kneading blade 38 and the kneading bolt 42 and thus a maximum shearing rate in the product mass P per shearing cycle owing to the sinusoidal axial movement of the respective kneading blade 38 on a line.

In the text which follows, the mode of operation of the plant for die casting die-cast parts which are optionally reinforced with nanoparticles and are made of an aluminum alloy is explained in more detail, by way of example, with reference to FIGS. 1 and 2.

An aluminum alloy melt kept just above the liquidus temperature of the alloy is fed to the working space 34 in metered form alone or together with nanoparticles via the introduction opening 50. The pinching of the partially solidified aluminum alloy with nanoparticles between the kneading blades 38 and the kneading bolts 42 results in the application of high shearing forces, which both lead to the comminution of dendritic branches and finely disperse the nanoparticles present in the form of agglomerates. Efficient, homogenizing mixing results from the combination of a radial and longitudinal mixing effect. By controlling the flow of cold and hot gases through the intermediate space 48 between the inner housing sleeve 32 and the outer housing sleeve 46, the solids content of the aluminum alloy in the working space 34 is set such that it is in the desired range when the metal is removed through the outlet opening 52.
[0026] The desired solids content of the aluminum alloy is set by measuring the change in viscosity of the metal melt in the kneading and mixing machine 30. The viscosity, which rises as the solids content of the partially solid aluminum alloy increases, can be determined, for example, by measuring the rotational resistance at the drive shaft 44 of the worm shaft 36. By determining the rotational resistance for defined solids contents, it is possible to specify appropriate setpoint values, to which measured actual values are regulated by controlling the flow of cold and hot gases through the intermediate space 48 between the inner housing sleeve 32 and the outer housing sleeve 46.

[0027] The aluminum alloy having the desired solids content and optionally comprising finely dispersed nanoparticles is introduced via the introduction opening 16 into the filling chamber 12 of the die-casting machine 10, and is injected intermittently from the latter into the mold cavity 14 of the casting mold from the filling chamber 12 in a known manner by means of the piston 20.

[0028] With reference to FIG. 5, the text which follows provides a more detailed explanation, by way of example, of the continuous production of partially solid, bar-shaped starting material for die casting die-cast parts which are optionally reinforced with nanoparticles and are made of an aluminum alloy. The mode of operation explained above with reference to FIGS. 1 and 2 is retained.

[0029] The aluminum alloy having the desired solids content and optionally comprising finely dispersed nanoparticles is continuously ejected via the outlet opening 52 in the form of a partially solid metal strand 70. Partially solid metal portions 72 are cut to length from the partially solid metal strand 70, for example using a rotating blade. The partially solid metal portions 72 usually each correspond to the quantity of metal required for producing an individual die-cast part and, for each shot, are transferred individually into the filling chamber 12 of the die-casting machine 10 and injected intermittently from the latter into the mold cavity 14 of the casting mold from the filling chamber 12 in a known manner by means of the piston 20.

[0030] The partially solid metal strand 70 usually leaves the mixing and kneading machine 30 in the direction of the longitudinal axis x of the worm shaft 36 in a horizontal direction, although another, e.g. vertical, outlet direction is also conceivable. The cross section of the metal strand 70 is determined by the cross section of the outlet opening 52, and is usually circular. The partially solid metal portions 72 can be grasped by tongs, for example, and transferred into the filling chamber 12 of the die-casting machine 10.

1. A process for producing die-cast parts made of an aluminum alloy, wherein the aluminum alloy is exposed to high shearing forces in a mixing and kneading machine, having a housing with a working space, which is surrounded by an inner housing sleeve, and a worm shaft, which rotates about a longitudinal axis and moves to and fro translationally in the longitudinal axis in the inner housing sleeve and is provided with kneading blades, and with kneading bolts, which are fastened to the inner housing sleeve and protrude into the working space, wherein liquid aluminum alloy is fed to the working space at one end of the housing and, at the other end of the housing, is removed from the working space as partially solid aluminum alloy with a predefined solids content, is transferred into a filling chamber of a die-casting machine and is introduced into a casting mold using a piston, wherein the solids content of the aluminum alloy in the working space is set to the predefined solids content by cooling and heating the working space in a targeted manner.

2. The process as claimed in claim 1, wherein the inner housing sleeve is surrounded by an outer housing sleeve such that an intermediate space is formed, and cold and/or hot gases are conducted through the intermediate space for cooling and heating the working space.

3. The process as claimed in claim 2, wherein air is conducted through the intermediate space for cooling, and hot gases are conducted through the intermediate space for heating.

4. The process as claimed in claim 2, wherein the gases are conducted through the intermediate space in countercurrent to the direction in which the aluminum alloy is transported.

5. The process as claimed in claim 1, wherein in order to set a desired solids content, the viscosity of the aluminum alloy in the working space is measured and set to a predefined value by cooling and heating the working space in a targeted manner.

6. The process as claimed in claim 1, wherein the solids content of the aluminum alloy is set to 40 to 80%.

7. The process as claimed in claim 1, wherein the partially solid aluminum alloy is removed from the working space as a partially solid metal strand, the partially solid metal strand is split into partially solid metal portions and the partially solid metal portions are transferred into the filling chamber of the die-casting machine.

8. The process as claimed in claim 1, wherein in order to produce die-cast parts reinforced with nanoparticles, nanoparticles are mixed with the aluminum alloy and finely dispersed in the aluminum alloy by high shearing forces in the mixing and kneading machine, wherein liquid aluminum alloy and nanoparticles are fed to the working space at one end of the housing and, at the other end of the housing, are removed from the working space as partially solid aluminum alloy with a predefined solids content and with nanoparticles finely dispersed in the aluminum alloy.

9. The process as claimed in claim 8, wherein the content of the nanoparticles in the alloy is 0.1 to 10% by volume.

10. The process as claimed in claim 9, wherein the nanoparticles are fumed silica, carbon nanotubes (CNT) or nanoscale particles of metal or semimetal oxides.

11. The process as claimed in claim 2, wherein the intermediate space is in the form of a hollow cylinder.

12. The process as claimed in claim 3, wherein the air is compressed air and the hot gases are combustion gases.

13. The process as claimed in claim 6, wherein the solids content of the aluminum alloy is set to 50 to 80%.

14. The process as claimed in claim 10, wherein the nanoscale particles of metal or semimetal oxides include aluminum oxide (Al₂O₃), titanium dioxide (TiO₂), zirconium oxide (ZrO₂), antimony(III) oxide, chromium(III) oxide, iron(III) oxide, germanium(IV) oxide, vanadium(V) oxide or tungsten (VI) oxide.

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