



(22) Date de dépôt/Filing Date: 2003/04/15

(41) Mise à la disp. pub./Open to Public Insp.: 2003/10/24

(30) Priorité/Priority: 2002/04/24 (02 405 339.9) EP

(51) Cl.Int.⁷/Int.Cl.⁷ B22D 13/02, B22D 46/00

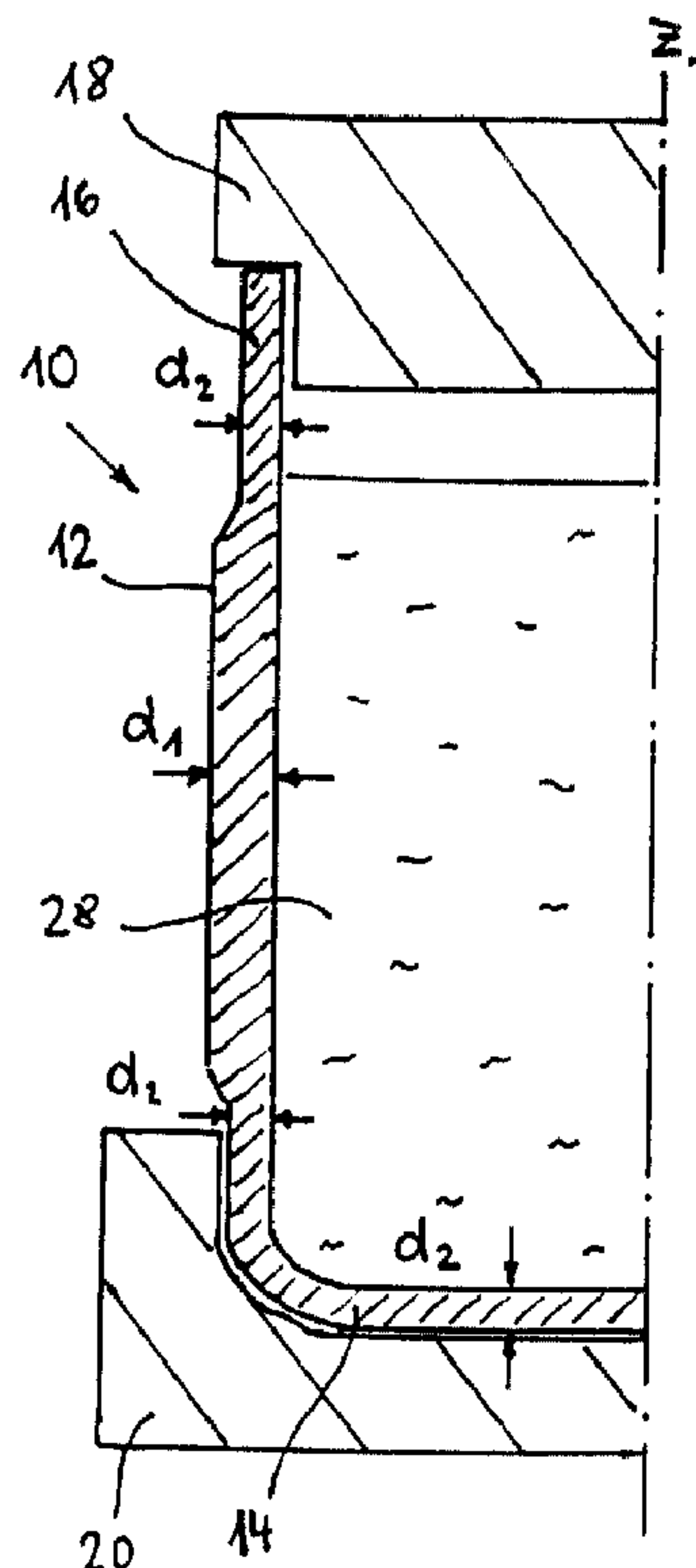
(71) Demandeur/Applicant:
ALCAN TECHNOLOGY & MANAGEMENT LTD., CH

(72) Inventeurs/Inventors:
WINKLER, REINHARD, DE;
HOLLRIGL, GUNTHER, CH;
ROHNER, WALTER, CH;
SCHELLING, HELMUT, CH;
BURBACH, THOMAS, CH

(74) Agent: OGILVY RENAULT

(54) Titre : METHODE DE TRANSFORMATION D'UN ALLIAGE METALLIQUE EN ARTICLE PROFILE
PARTIELLEMENT SOLIDE ET LIQUIDE

(54) Title: PROCESS FOR TRANSFORMING A METAL ALLOY INTO A PARTIALLY-SOLID/PARTIALLY LIQUID
SHAPED BODY



(57) Abrégé/Abstract:

The invention relates to a process for transforming a metal alloy (28) having a liquidus temperature and a solidus temperature into a part solid/part liquid shaped body. The metal alloy (28) is poured in the molten state at a temperature (T_{Mo}) into a mould (10) having an essentially cylindrical mould wall (12), whereby the mould (10) at the start of filling exhibits a starting temperature



(57) Abrégé(suite)/Abstract(continued):

that lies below the liquidus temperature, the mould (10) is set into an eccentric rotational movement at a starting temperature for the metal alloy (28) lying above the liquidus temperature and the rotational movement maintained until the metal alloy (28) has cooled to a discharging temperature lying between the liquidus temperature and the solidus temperature corresponding to a desired solid/liquid ratio in the shaped body and the shaped body removed from the mould (10) at the discharging temperature. In order to set a desired cooling rate of the metal alloy (28) in the mould (10), the thickness (d_1) of the mould wall (12), the material and the starting temperature of the mould (10) are selected such that the change in enthalpy of the metal alloy (28), during cooling from the pouring temperature to the discharging temperature, is smaller than the change in enthalpy for an increase in temperature of the mould (10) from the starting temperature to its final temperature. The setting of the parameters influencing the cooling rate of the mould in combination with the eccentric rotation of the mould lead to an optimal, short duration of the process.

Abstract

The invention relates to a process for transforming a metal alloy (28) having a liquidus temperature and a solidus temperature into a part solid/part liquid shaped body., The metal alloy (28) is poured in the molten state at a temperature (T_{Mo}) into a mould (10) having an essentially cylindrical mould wall (12), whereby the mould (10) at the start of filling exhibits a starting temperature that lies below the liquidus temperature, the mould (10) is set into an eccentric rotational movement at a starting temperature for the metal alloy (28) lying above the liquidus temperature and the rotational movement maintained until the metal alloy (28) has cooled to a to a discharging temperature lying between the liquidus temperature and the solidus temperature corresponding to a desired solid/liquid ratio in the shaped body and the shaped body removed from the mould (10) at the discharging temperature. In order to set a desired cooling rate of the metal alloy (28) in the mould (10), the thickness (d_1) of the mould wall (12), the material and the starting temperature of the mould (10) are selected such that the change in enthalpy of the metal alloy (28), during cooling from the pouring temperature to the discharging temperature, is smaller than the change in enthalpy for an increase in temperature of the mould (10) from the starting temperature to its final temperature.

The setting of the parameters influencing the cooling rate of the mould in combination with the eccentric rotation of the mould lead to an optimal, short duration of the process.

(Fig. 1)

Process for Transforming a Metal Alloy into a Partially-Solid/Partially-Liquid Shaped Body

The invention relates to a process for transforming a metal alloy having a liquidus temperature and a solidus temperature into a partially/solid/partially/liquid shaped body, in which process the metal alloy is poured in the liquid state at a pouring temperature into a mould having an essentially cylindrical mould wall, whereby the mould at the start of the filling stage exhibits an initial temperature that lies below the liquidus temperature and the metal alloy is kept in the mould until it has cooled to a discharging temperature lying between the liquidus temperature and the solidus temperature corresponding to the desired solid / liquid ratio in the shaped body, and the shaped body is removed from the mould at the discharging temperature.

Part-solid/part-liquid shaped bodies with thixotropic properties can be made from metal alloys. Because of the thixotropic properties, the shaped bodies can be processed further e.g. on a die-casting machine.

In a first, known process, so-called thixocasting, a metal alloy is cast to billet form by means of continuous casting. In order to achieve the fine-grained structure necessary for the thixotropic properties, the molten metal is stirred vigorously in the solidification range i.e. between the liquidus and solidus temperature of the metal alloy, whereby in particular electromagnetic stirring devices have proved to be effective for that purpose. The stirring action causes the dendrites that are forming to be sheared or retarded in such a manner that these primary solidifying solid particles take on an essentially globulitic form. The solidified billet is divided into shaped bodies which, after heating to a temperature between the solidus and liquidus temperature of the alloy, exhibit thixotropic properties. In the thixotropic state, reached after heating the shaped body in this manner, the metal alloy contains the retarded dendritic, primary solidified and essentially globulitic particles in a surrounding matrix of liquid metal.

In another known process - so called rheocasting – a metal alloy melt is produced in a continuous manner with a solid fraction corresponding to the solid/liquid ratio desired in the shaped body. As in the first mentioned process, the metal melt is stirred vigorously in the temperature range between the alloy solidus and liquidus in order to create the fine grained structure required for the thixotropic properties. Compared with thixocasting, rheocasting offers a significant advantage in terms of energy and therefore costs; however, rheocasting units require complicated and difficult processes in order to ensure coordination with a subsequent casting machine to manufacture the final product.

In the case of a process known from EP-A-0 745 694 a metal alloy containing nucleating crystals is cast in a thermally insulated mould. As soon as the desired solid/liquid ratio has been established in the metal alloy, after appropriate cooling, the resultant part-solid/part-liquid shaped body is advanced for further processing.

In a process published in WO-A-01/07672 the metal alloy is cast in a mould, cooled to the discharging temperature between the liquidus and solidus temperatures corresponding to the desired solid/liquid ratio, and held for a specific time at the discharging temperature in order to form the structure in the resultant shaped body. Thereby, the mould parameters are selected specifically for the metal alloy such that the change in enthalpy of the mould on heating from the starting temperature to a final temperature is the same as the change in enthalpy of the metal alloy on cooling from the temperature of the melt when poured into the mould to the discharging temperature at which the desired solid/liquid ratio is established in the metal alloy. The final temperature for the mould corresponds to the discharging temperature i.e. the metal alloy and the mould both reach their thermal equilibrium at the discharging temperature. In order to accelerate the reaching of thermal equilibrium, the mould may e.g. be subjected to eccentric rotation during the cooling of the metal alloy.

The disadvantage of both of the above mentioned processes lies in the relatively long process time i.e. the duration of time from pouring the metal alloy into the form or moving the molten metal until removal of the shaped body from the mould. For efficient production of shaped bodies it is therefore necessary to
5 provide several stations for manufacturing shaped bodies.

The object of the present invention is to provide a process of the kind described at the start which, using simple means, permits the cooling conditions to be reached in an optimal manner with the result that a shaped body can be
10 produced in the shortest possible time and without forming a peripheral zone.

That objective is achieved by way of the invention in that, in order to set a desired cooling rate of the metal alloy in the mould, the thickness of the mould wall, the material and the initial temperature of the mould are selected such that
15 the change in enthalpy of the metal alloy during cooling from the pouring temperature to the discharging temperature is smaller than the change in enthalpy for an increase in temperature of the mould from the initial temperature to its final temperature.

20 As a result of the thermal non-equilibrium between the mould and the metal alloy that prevails at the discharging temperature, setting the parameters that influence the cooling rate of the mould in a manner according to the invention leads to an optimal and, in comparison to the state-of-the-art, short duration of the process. By duration of the process is to be understood, here and in the
25 following, the time of cooling the metal alloy from the pouring temperature or, if the molten melt is moved i.e. agitated from the temperature at the start of agitation, to the discharging temperature. The discharging temperature is the temperature of the mould at the point in time when the shaped body is removed from the mould.

30

In a first preferred version of the process according to the invention the temperature over a period of time is employed to determine the time for

discharging. The discharging takes place on reaching a given target value of temperature profile in the metal alloy and a given target value of discharging temperature. The time required to reach the discharging temperature in order to obtain a good, homogeneous shaped body depends on the composition of the alloy.

In a second preferred version of the process according to the invention the temperature change as a function of time at a fixed point in the mould wall is chosen to determine the time for discharging. The discharging takes place on reaching a given target value of temperature gradient and a given target value of discharging temperature.

The initial temperature of the mould lies preferably between room temperature and approximately 320°C.

The shaped body is normally removed from the mould immediately on reaching the discharging temperature and advanced for further processing. For the case in which the discharging can not be carried out immediately, e.g. if the production unit is defective, it is possible using the process according to the invention to maintain the shaped body at the discharging temperature by heating the mould until the problem has been solved.

The duration of the process can be optimised further in that the metal alloy is agitated and the agitation is maintained until the metal alloy has cooled to the discharging temperature. The agitation of the metal alloy may be performed in principle using all known means e.g. by electromagnetic stirring or by movement of the mould. The purpose of moving the mould is to produce flow behaviour in the molten melt or later in the partially solid / partially liquid melt. The primary aim is to achieve good mixing without causing vortices or currents. In the interest of the process, the agitation should be such that it starts as soon as possible after pouring metal into the mould as the viscosity of the cooling, partly solidified metal alloy increases continuously, and effective agitation is

increasingly difficult to achieve. The movement of the mould is set such that at the start the metal alloy does not splash out of the mould; this can be achieved e.g. by agitating the melt with low intensity in the initial phase and increasing the intensity with increasing viscosity.

5

An optimum process duration is achieved when immediately after completed filling of the mould the mould is made to rotate in an eccentric manner and the rotational movement is maintained until the metal alloy has cooled to the discharging temperature. An eccentric movement of the mould means that the
10 mould axis is in a distance from the axis of rotation and rotates about that, whereby the mould itself does not rotate about its own axis.

The rotational movement is preferably started when the starting temperature of the metal alloy lies in the area of the liquidus temperatures or slightly above the
15 liquidus temperatures, whereby the starting temperature of the metal alloy preferably lies 5 to 15°C above the liquidus temperature.

The speed of rotation normally lies approx. between 50 to 500 rpm and is preferably increased with progressive cooling of the metal alloy because of the
20 rising viscosity.

The rotational movement which is applied over the whole duration of the process is preferably divided into two, preferably three cycles, whereby the maximum speed of rotation in each cycle is greater than the speed of rotation in
25 the previous cycle. Usefully, the start up procedure for each rotation cycle is such that the maximum speed of rotation is reached after 10 to 20 seconds.

Particularly good mixing of the metal alloy with optimum removal of heat through the mould wall is achieved by the combination of each rotation cycle
30 with a shaking cycle, whereby the shaking cycle follows on from the rotation cycle or overlaps the rotational movement.

In a preferred version of the process according to the invention the first two rotation cycles are carried out within an overall time of 30 to 50 sec.

5 The shaking cycle comprises a shaking movement with a frequency of 2 to 3 Hz over a maximum interval of 10 sec, preferably 1 to 6 sec.

The rotational movement is preferably started when the starting temperature of the metal alloy lies 5 to 15°C above the liquidus temperature.

10 In particular aluminium alloys can be processed using the process according to the invention.

Hereby the alloy may exhibit a eutectic solidus temperature with a significant volume fraction of eutectic melt. Such alloys belong e.g. to the Al-Si system with
15 2.5 – 10 wt.% Si or to the quasi-binary Al-Mg₂Si system with 4 wt.% Si and 2 – 6 wt.% Mg.

Other alloys which can be processed are, however, alloys which do not exhibit a eutectic melting point, e.g. an alloy of the AlMg₃Mn type.

20

In order to obtain uniform withdrawal of heat in an essentially radial direction, the thickness of the mould wall in the region of the head and base of the mould can be reduced compared with the thickness of the wall between the head and the base. Another possibility is to insulate the base and the head of the mould
25 with respect to its surroundings.

In order to facilitate the removal of the shaped body from the mould, the base of the mould may be designed such that it is hinged. The shaped body can then be removed

In order to make it easier to remove the shaped body from the mould, the mould wall may be conically broadened from the base of the mould to the top. In the

case of a mould with a hinged i.e. openable base, the conical broadening of the mould wall may also run from top to bottom.

In a preferred version of the mould, this is divided in the longitudinal direction and the shaped body removed from the mould after separating the two parts of the mould. This makes it possible to open the mould and to remove the shaped
 5 body e.g. using a robot arm in such a manner that the shaped body can be introduced horizontal into the chamber of a diecasting machine. Such a manner of handling is important in order to reduce the amount of deformation of the shaped body due to its own weight (so called "elephant foot").

10 The time-dependent non-stationary temperature field in the mould wall may be employed to supervise and regulate heat extraction for determining the optimal discharging temperature and with that the optimal duration of the process from the starting temperature to the discharging temperature.

15 By employing the functional relationship for a minimum process time t_{pr}

$$t_{pr} = f(\Delta H_M, T_{AM}, T_{EM}, d_1, T_W(t, d_1), T_{AF}, Fo) \Rightarrow \min.$$

ΔH_M Change in enthalpy of the metal melt between T_{AM} and T_{EM}

T_{AM} Temperature of the melt at the start of the rotational movement (starting temperature)

T_{EM} Temperature for discharging the shaped body from the mould

d_1 Thickness of the mould wall

T_w Temperature of a mould wall element during the process

T_{AF} Initial temperature in the mould wall (pre-heat temperature)

Fo Fourier coefficient

20 it is possible to simulate and regulate the whole process on the basis of Fourier coefficients for the conduction of heat in the mould wall.

Further advantages, features and details of the invention are revealed in the following description of preferred exemplified embodiments of the invention and with the aid of the drawing which shows schematically in:

- 5 Fig. 1 a longitudinal section through a part of a mould;
- Fig. 2 a side elevation of a divided mould;
- Fig. 3 plan view of an arrangement with a cylindrical mould subjected to eccentric rotation.

10 A mould 10 shown in fig. 1 made e.g. of steel comprises a cylindrical mould wall 12 with an axis of symmetry z_1 . The mould 10 is closed on one side by a base 14. The head 16 which is open at the top is covered over by a lid 18 made of thermally insulating material. The base sits in a lower part 20 made of thermally insulating material. The liquid/solid metal mixture 28 is situated in the
15 interior of the mould 10.

The cylindrical mould wall 12 is thicker between the head 16 and the base 14. For example the thickness d_1 of the wall 12 in the thicker part of the mould is 5 mm, while the thickness d_2 of the base 14 and the head 16 is 3 mm.

20

With the arrangement shown in figure 1 the extraction of heat from the metal melt into the mould wall is more uniform and takes place essentially in a radial direction.

25 The mould 10 shown in figure 2 is divided along its axis i.e. in the longitudinal direction. Both parts 10a,b of the mould can be separated for removal of the shaped body from the mould.

The influence of eccentric rotation on the movement of the molten melt in the
30 mould 10 is clear from figure 3. The mould 10 is e.g. mounted on a plate. The axis of symmetry z_1 of the mould 10 is a distance a from an axis of rotation z_2 . The axis z_1 of the mould 10 rotates around the axis z_2 , whereby, however, the

mould itself does not rotate around its own axis. Shown in figure 3 are the circular paths of a point on the mould wall 12 and a point in the centre of the mould 10. For a radius r in the cylindrical inner wall of the mould and a value a of eccentricity, which corresponds to the radius of the circular path, the inner wall of the mould rolls on a circular path with a radius $R = r + a$. The described eccentric rotation of the mould 10, together with a resultant rotational movement of the melt, leads to thorough homogeneous mixing of the melt. This thorough mixing concerns both the alloying elements and the temperature.

10 Examples

The advantage of the process according to the invention is illustrated in the following by way of processing four different alloys 1 to 4 into shaped bodies. The chemical compositions of the Al 99.85 based alloys used for the trials are summarised in table 1.

15

Table 1

Alloy	Si [wt %]	Mg [wt %]	Mn [wt %]	Fe [wt %]	Ti [wt %]
1	7.0	0.3	-	0.1	0.06
2	2.2	5.2	0.6	0.1	0.08
3	0.1	3.0	0.1	-	0.08
4	4.5	0.3	-	0.1	0.06

The alloys were poured in the molten state into a steel cylindrical mould, the inner wall of which had been coated with a slurry to prevent sticking. The inner diameter of the mould was 100 mm and the wall thickness d_1 lay between 2 and 7 mm; the mould was filled to a depth of 260 mm. In some of the trials the mould was pre-heated before receiving the molten metal. As soon as the metal melt, which was cooling from the pouring temperature, reached the starting temperature, the mould was set into an eccentric rotational movement and maintained so until the discharging temperature was reached.

The eccentric rotational movement was investigated under the following conditions for a degree of eccentricity of 6.5 mm:

- 5 A 15 sec at 140 rpm + 15 sec at 200 rpm + 250 rpm until discharging
 B constant at 140 rpm until discharging

On removal of the shaped body from the mould quality assessment is carried out via simple mechanical testing of a prematurely solidified edge shell, the appearance of which can lead to a reduction in quality of the final product resulting from further processing of the shaped body. The process parameters and the results achieved with these are summarised in table 2.

Table 2

Alloy	T _L [°C]	T _S [°C]	d ₁ [mm]	T _{Mo} [°C]	T _{AM} [°C]	T _{AF} [°C]	Ro- tat.	t _{pr} [s]	T _{EM} [°C]	Quality of the shaped body
1	610	566	2	640	615	RT	A	420	585	very good
1	610	566	5	640	615	RT	A	102 – 115	578 – 583	very good
1	610	566	7	640	615	RT	A	52	586	edge shell
1	610	566	7	640	615	50	A	57	595	edge shell
1	610	566	7	640	615	150	A	70	590	very good
1	610	566	7	640	615	200	A	85	590	very good
1	610	566	7	640	615	300	A	140	590	very good
2	620	594	5	660	635	RT	B	50 – 55	600	edge shell
2	620	594	5	660	635	200	B	85	600	edge shell
2	620	594	5	660	635	300	B	180	600	very good
3	640	600	5	680	655	RT	B	35 – 40	633	very good
3	640	600	2	645	645	RT	A	300	634	very good

Alloy	T_L [°C]	T_S [°C]	d₁ [mm]	T_{Mo} [°C]	T_{AM} [°C]	T_{AF} [°C]	Ro- tat.	t_{pr} [s]	T_{EM} [°C]	Quality of the shaped body
4	630	566	5	635	635	RT	B	58 - 70	607 - 610	very good

T_L Liquidus temperature of the alloy

T_S Solidus temperature of the alloy

d₁ Wall thickness of the mould

5 T_{Mo} Temperature of the molten metal poured into the mould

T_{AM} Starting temperature at the start of the eccentric movement of the mould

T_{AF} Initial temperature of the mould (pre-heat temperature)

t_{pr} Duration of the process (time from the start of the eccentric rotational movement until discharging from the mould)

10 T_{EM} Discharging temperature

Claims

1. Process for transforming a metal alloy (28) having a liquidus temperature (T_L) and a solidus temperature (T_S) into a partially solid/partially liquid shaped body, in which process the metal alloy (28) is poured in the liquid state at a pouring temperature (T_{M0}) into a mould (10) having an essentially cylindrical mould wall (12), whereby the mould (10) at the start of the filling stage exhibits an initial temperature (T_{AF}) that lies below the liquidus temperature (T_L) and the metal alloy (28) is kept in the mould (10) until it has cooled to a discharging temperature (T_{EM}) lying between the liquidus temperature (T_L) and the solidus temperature (T_S) corresponding to a desired solid/liquid ratio in the shaped body and the shaped body is removed from the mould (10) at the discharging temperature (T_{EM}),

characterised in that,

in order to set a desired cooling rate of the metal alloy (28) in the mould (10), the thickness (d_1) of the mould wall (12), the material and the initial temperature (T_{AF}) of the mould (10) are selected such that the change in enthalpy (ΔH_M) of the metal alloy (28) during the cooling from the pouring temperature (T_{M0}) to the discharging temperature (T_{EM}) is smaller than the change in enthalpy (ΔH_F) for an increase in temperature of the mould (10) from the initial temperature (T_{AF}) to its final temperature (T_{EF}).

2. Process according to claim 1, characterised in that the change in temperature $T(t)$ as a function of time is employed to determine the time for discharging, whereby the discharging takes place on reaching a given target value of temperature profile in the metal alloy (28) and a given target value of discharging temperature (T_{EM}).
3. Process according to claim 1, characterised in that the change in temperature $T(t)$ as a function of time at a fixed point in the mould wall (12) is

employed to determine the time for discharging, whereby the discharging takes place on reaching a given target value of temperature gradient dT_W/dt and a given target value of discharging temperature (T_{EM}).

4. Process according to one of the claims 1 to 3, characterised in that the initial temperature (T_{AF}) of the mould (10) lies between room temperature and 320°C.
5. Process according to one of the claims 1 to 4, characterised in that the discharging of the shaped body (12) takes place immediately after reaching the discharging temperature (T_{EM}).
6. Process according to one of the claims 1 to 4, characterised in that, on reaching the discharging temperature (T_{EM}), the shaped body (12) is held at the discharging temperature (T_{EM}) by heating the mould (10) and discharged after a holding time.
7. Process according to one of the claims 1 to 6, characterised in that the metal alloy (28) is made to move and the movement of the metal alloy (28) is maintained until it has cooled to the discharging temperature (T_{EM}).
8. Process according to claim 7, characterised in that immediately after completed filling of the mould the mould (10) is made to rotate in an eccentric manner and the rotational movement is maintained until the metal alloy (28) has cooled to the discharging temperature (T_{EM}).
9. Process according to claim 8, characterised in that the rotational movement is started when the starting temperature (T_{AM}) of the metal alloy (28) lies in the area of the liquidus temperature (T_L) or slightly above the liquidus temperature (T_L) whereby the starting temperature (T_{AM}) of the metal alloy (28) preferably lies 5 to 15°C above the liquidus temperature (T_L).

10. Process according to claim 8 or 9, characterised in that the speed of rotation lies between 50 and 500 rpm.
11. Process according to claim 10, characterised in that the speed of rotation is increased with progressive cooling of the metal alloy (28).
12. Process according to one of the claims 8 to 11, characterised in that the rotational movement features at least two, advantageously three cycles with increasing speed of rotation.
13. Process according to claim 12, characterised in that a shaking cycle follows each rotational cycle or is superimposed on the rotational movement.
14. Process according to claim 12 or 13, characterised in that the first two rotation cycles are carried out within an overall time of 30 to 50 seconds.
15. Process according to claim 13 or 14, characterised in that the shaking cycle comprises a shaking movement lasting at most 10 sec., preferably 2 to 6 sec.
16. Process according to one of the claims 1 to 15, characterised in that the metal alloy (28) is an aluminium alloy.
17. Process according to claim 16, characterised in that the alloy exhibits a eutectic solidus temperature with a significant volume fraction of eutectic melt.
18. Process according to claim 17, characterised in that the alloy belongs to the AlSi system with a Si content of 2.5 to 10 wt.% or to the quasi-binary Al-Mg₂Si system with a Si content of 1.5 - 4 wt.% and a Mg content of 2 - 6 wt.%.

19. Process according to claim 16, characterised in that the alloy does not exhibit a eutectic melting point and is preferably of the AlMg3Mn type.
20. Process according to one of the claims 1 to 19, characterised in that, in order to achieve uniform removal of heat in an essentially radial direction, the thickness (d₁) of the mould wall (12) in the region of the head (16) and the base (14) of the mould (10) is reduced in comparison with the wall thickness (d₂) in the region between the head and the base.
21. Process according to one of the claims 1 to 20, characterised in that in order to achieve uniform removal of heat in an essentially radial direction, the base (14) and the head (16) of the mould (10) are insulated from their surroundings.
22. Process according to one of the claims 1 to 21, characterised in that, in order to remove the shaped body (12) from the mould (10), the base (14) of the mould (10) is hinged for opening.
23. Process according to one of the claims 1 to 21, characterised in that, in order to remove the shaped body (12) from the mould (10), the mould wall (12) is conical broadened from the base (14) of the mould (10) to the head (16).
24. Process according to one of the claims 1 to 21, characterised in that the mould (10) is divided in the longitudinal direction and the shaped body (12) is removed from the mould (10) after separating both mould parts (12a,b).
25. Process according to one of the claims 1 to 24, characterised in that, after removal from the mould (10), the shaped body is preferably shape-formed in a pressure diecasting machine.

26. Process according to one of the claims 1 to 25, characterised in that the time-dependent, non-stationary temperature field in the mould wall (12) is employed to supervise and regulate heat extraction for determination of the optimal discharging temperature (T_{EM}) and with that the optimal process time from the starting temperature (T_{AM}) to the discharging temperature (T_{EM}).
27. Process according to one of the claims 1 to 26, characterised in that the overall process is simulated and regulated on the basis of the Fourier coefficients for thermal conduction in the mould wall (12) using the functional relationship for a minimum process time t_{pr}

$$t_{pr} = f(\Delta H_M, T_{AM}, T_{EM}, d_1, T_w(t, d_1), T_{AF}, Fo) \Rightarrow \min.$$

ΔH_M	enthalpy change in the metal melt between T_{AM} and T_{EM}
T_{AM}	Melt temperature at the start of the rotational movement (starting temperature)
T_{EM}	Temperature at which the shaped body is discharged from the mould
d_1	Thickness of the mould wall
T_w	Temperature of a mould wall element during the course of the process
T_{AF}	Initial temperature in the mould wall (pre-heat temperature)
Fo	Fourier coefficient

1/2

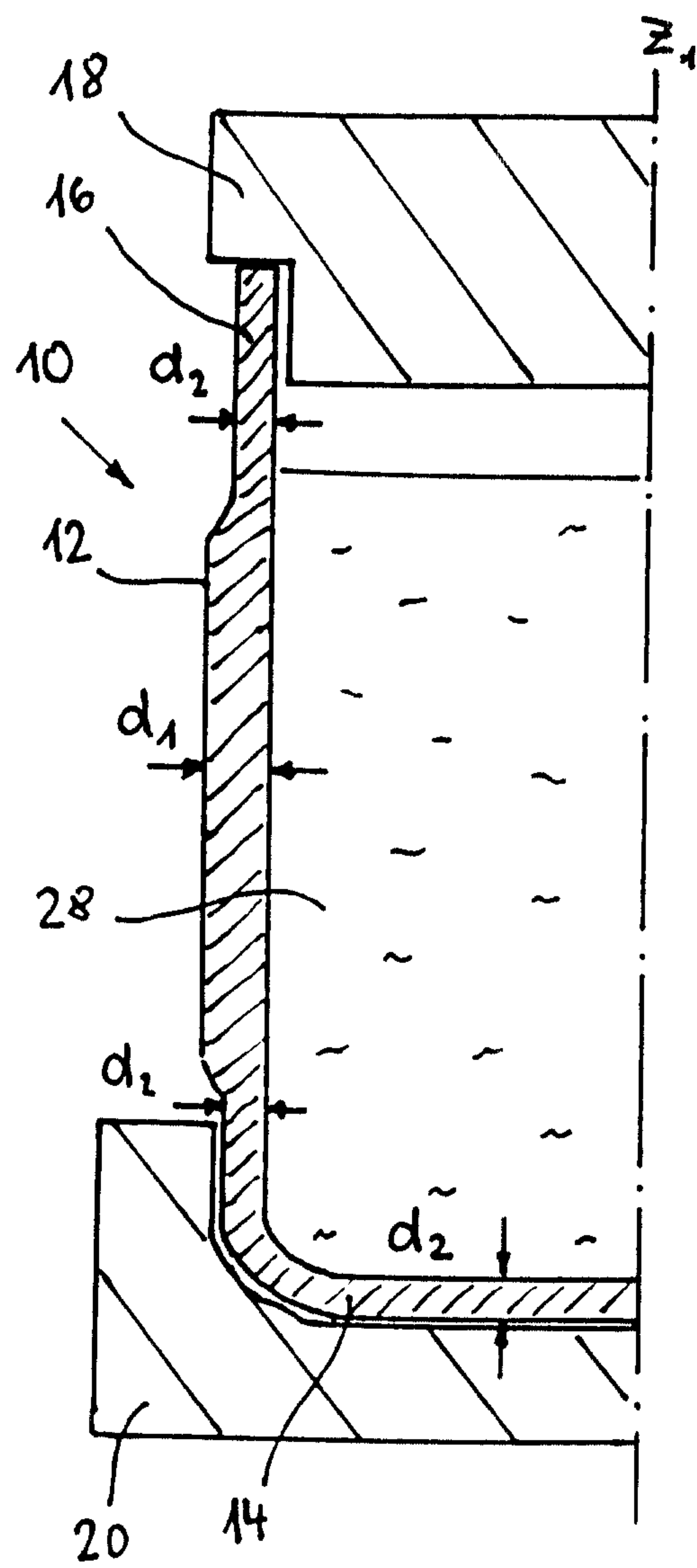
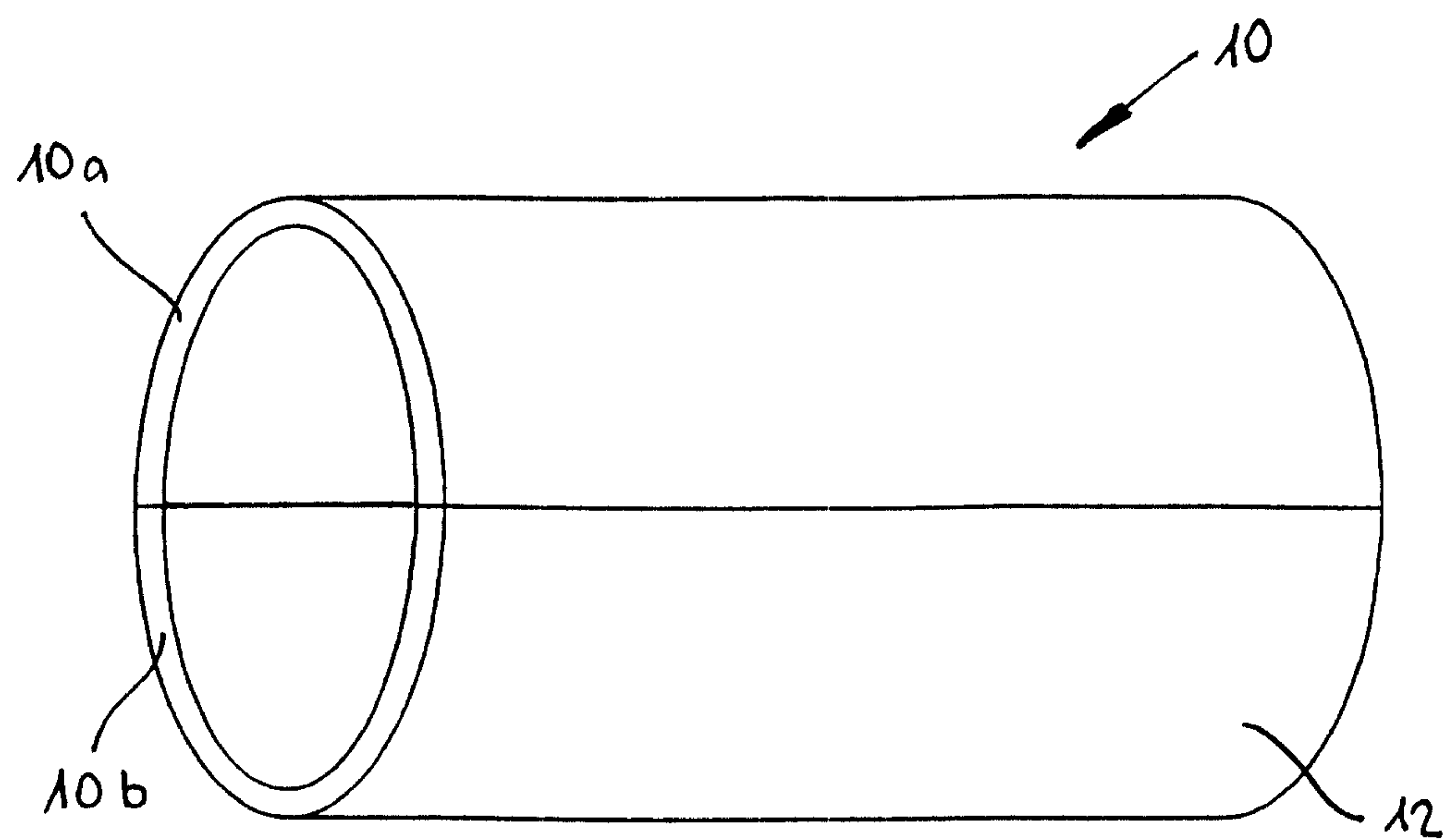
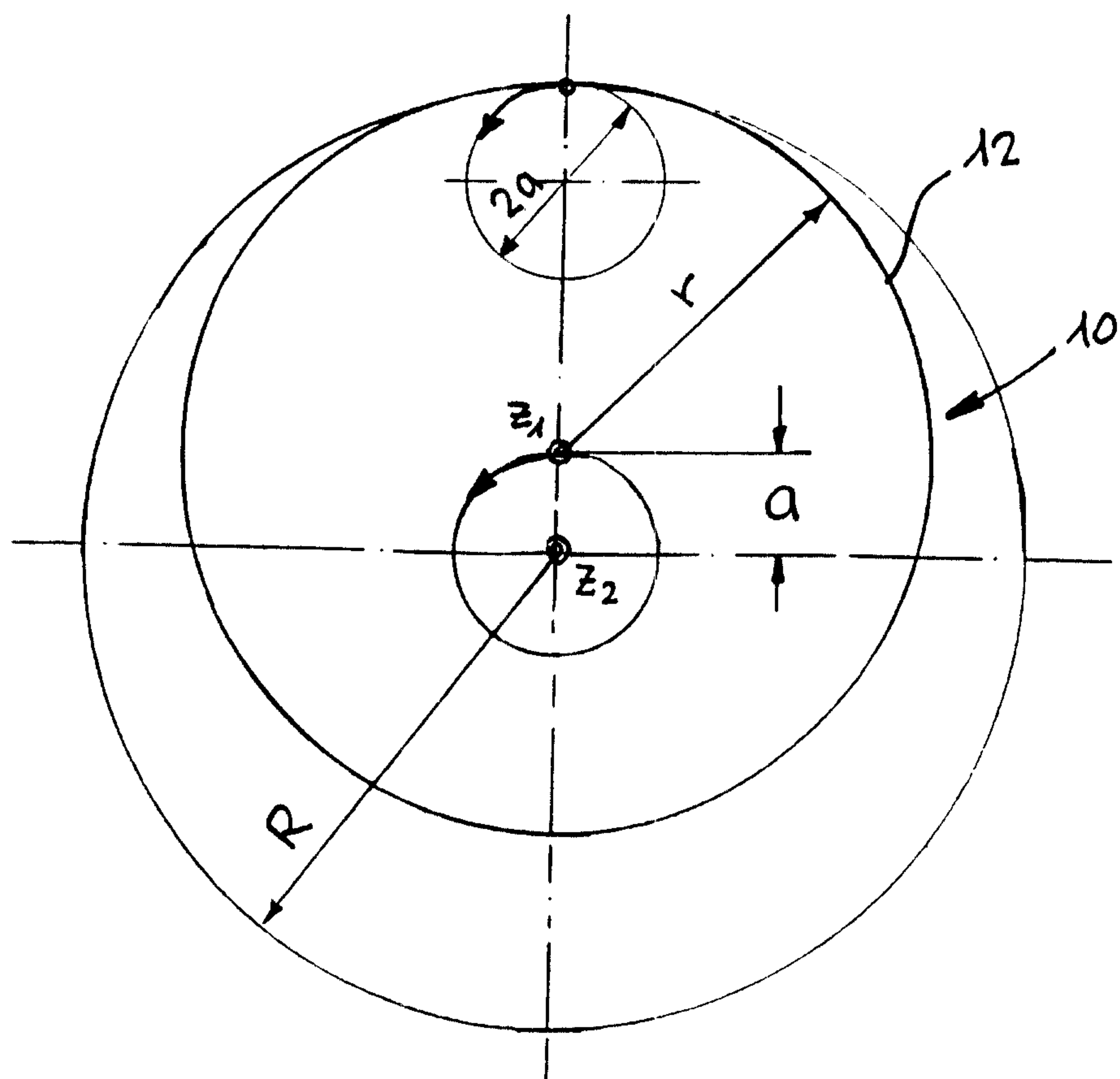


Fig. 1

2/2

**Fig. 2****Fig. 3**

