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(54) Die casting process for producing high mechanical performance components via injection of a semiliquid metal alloy.

(57) A die casting process, in particular, for producing light alloy internal combustion engine components, whereby a metal alloy in pigs, possibly containing ceramic particles, is melted and cast in semiliquid form into ingots (8), by feeding it, as it solidifies and under laminar flow conditions, through a static mixer (3). The ingots are then divided, e.g. cut, into smaller ingots (12), each of the same weight as the component for casting, which are heated to paste form in a furnace at a temperature within the solidification range of the alloy, and then fed one at a time into the injection chamber (20) of a die casting machine by which the semiliquid alloy of which the ingot is formed is injected into a mold (22).

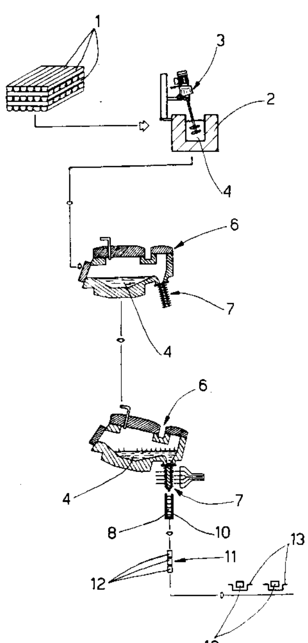

Fig.1

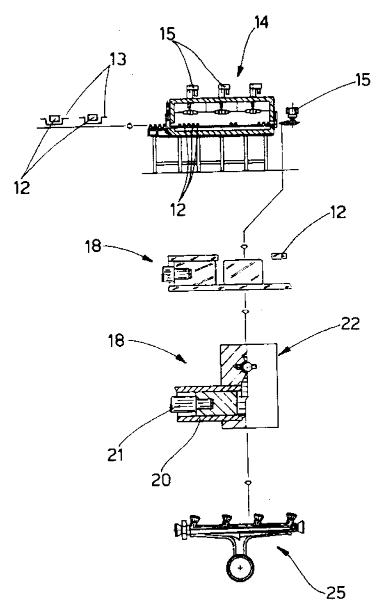

Fig.2

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The present invention relates to a die casting process for producing internal combustion engine components from a light alloy, in particular, aluminium alloy to which ceramic particles are added.

Italian Patent n.1.119.287 filed on 20 June, 1979, and entitled: "Process and device for preparing a metal alloy mixture comprising a solid and liquid phase", the content of which is incorporated herein purely by way of reference as required, relates to a static mixer consisting of a cylindrical runner housing a series of helical blades, for casting and partially solidifying a metal alloy as it is fed through the mixer, while at the same time mixing the newly formed solid phase with the remaining liquid phase. This produces, at the output of the mixer, a relatively low-viscosity solid/liquid mixture in which the solid phase of the alloy is uniformly suspended in the liquid alloy.

For the solid/liquid mixture to remain stable long enough for ladling and casting, it must be produced under steady fluid dynamic conditions, with accurate, rapid control of the physical and dynamic parameters involved in the casting process (temperature, alloy cooling rate, speed through the mixer, etc.). For this purpose, the present Applicant has perfected a semiliquid casting process as described in Italian Patent Application n.67 627-A/89, filed on 25.07.1989, and entitled: "Continuous semiliquid casting process and furnace", the content of which is incorporated herein purely by way of reference as required. According to the above process, the static mixer is connected to a pressurized tiltable reverberatory furnace, for casting under steady conditions, and is equipped with a barometric column enabling it to be refilled without interrupting or affecting steady flow of the casting.

Metal alloys produced using semiliquid casting processes as described above are said to be "rheocast", and present particularly good microstructural characteristics. Rheocast light alloys, in fact, have recently be found to present a globular as opposed to a traditional dendritic microstructure, thus resulting in improved fluid dynamic characteristics (temperatures within the solidification range). Despite the above advantages, however, known semiliquid casting processes have yet to be applied to the manufacture of internal combustion engine components, which, for cost reasons, are normally die cast. A major drawback of die casting is the formation of blowholes in the casting, resulting from the turbulence produced by the high speed at which the liquid alloy is injected. Another drawback is inevitable shrinkage of the casting as it solidifies, and which is proportional to the temperature at which the alloy is injected (which, for liquid aluminium alloy is usually 700 °C). Though cheap to produce, the poor quality of current die cast components therefore makes the use of finer quality alloys unfeasible.

Apart from the fact that they cannot be used for die casting, the above consideration also applies to various recently marketed alloys reinforced with ceramic particles to give 20 to 30% greater mechanical strength as compared with nonreinforced alloys of the same type. In fact, even assuming the reinforcing particles (which, being ceramic, melt at a much higher temperature than light alloy) could be maintained evenly dispersed in the molten alloy, e.g. by stirring it, the problem still remains of preventing the particles from separating from the alloy and accumulating in one part of the casting by force of gravity and, more especially, the dynamic thrust exerted on the particles as the molten alloy is fed, in this case, under turbulent flow conditions, through the gate.

It is an object of the present invention to provide a process enabling low-cost manufacture of metal alloy die castings with substantially no defects, and using fine quality metal alloys, possibly also containing uniformly dispersed ceramic reinforcing elements.

According to the present invention, there is provided a process for producing die castings, in particular, light alloy internal combustion engine components, characterized by the fact that it comprises stages consisting in:

- melting a metal alloy until it is fully liquid;
- casting said metal alloy in semiliquid form by feeding it, as it solidifies and under laminar flow conditions, through a static mixer for mixing the liquid alloy uniformly with a solid phase, which separates from the liquid alloy to produce a temporary stable solid-liquid suspension at the output of the mixer;
- solidifying said solid-liquid suspension into rheocast ingots wherein the metal alloy presents a globular micrographic structure;
- dividing said rheocast ingots into a number of ingots of predetermined weight;
- heating said ingots to a temperature within the solidification range of said metal alloy, to convert the globular-structure metal alloy into paste form;
- feeding said ingots, one at a time, into the injection chamber of a die casting machine; and
- injecting said globular-structure alloy, heated to a temperature within the solidification range of the alloy, into a mold.

According to the present invention, there is also provided a process for die casting aluminium alloy, characterized by the fact that it consists in heating an ingot, produced by casting said alloy in semiliquid form to produce a globular micrographic structure of the alloy, to a temperature within the solidification range of the alloy and such as to reduce the alloy to a highly viscous, semiliquid form; and in subsequently exerting mechanical pressure on the ingot.

A non-limiting embodiment of the present invention will be described by way of example with reference to the accompanying drawings, in which:

Fig.s 1 and 2 show schematic views of the various stages in the process according to the present invention;

Fig.s 3 and 4 show respective microphotographs of the same metal alloy before and after certain stages in the process according to the present invention.

With reference to Fig.s 1 and 2, pigs 1 of a metal alloy, in the example shown, light aluminium-based casting alloy UNI 3600 (UNI coding) are first melted normally in a known pot furnace 2. According to a preferred embodiment of the present invention, the initial alloy is A356, a casting alloy produced and marketed by ALCAN of San Diego (CA) U.S.A., which presents a nominal matrix of 93% Al and 7% Si in which is dispersed uniformly a ceramic phase consisting, in this case, of SiC (silicon carbide) particles. These, with a volumetric percentage of 20% for a given composition, provide for a roughly 30% improvement in the mechanical characteristics of the alloy and, in particular, a roughly 35% reduction in thermal expansion, which is thus similar to that of steel. In this case, furnace 2 is equipped with a known mechanical mixer 3 (or other similar known means not shown for the sake of simplicity) for maintaining the SiC particles uniformly dispersed in the molten alloy.

Once the initial alloy is fully liquefied (except for any suspended SiC particles, which melt at a much higher temperature than the alloy), the resulting liquid phase 4 (possibly also containing solid SiC particles) is fed into a pressurized rocking furnace 6 as described in Italian Patent Application n. 67627-A/89, filed by the present Applicant on 25.07.1989, and the content of which is incorporated herein purely by way of reference as required; which furnace 6 is connected to a known static mixer 7 as described in Italian Patent n. 1.119.287 filed on 20 June, 1979, and the content of which is also incorporated herein purely by way of reference as required.

Liquid phase 4 is then cast as described in the above patents, the mixer 7 being cooled so as to separate from liquid phase 4, as it is fed through mixer 7, a solid phase (not shown) which gradually increases as the alloy is cooled through mixer 7, and which is mixed uniformly with liquid phase 4 to produce a temporary stable solid-liquid suspension 8 at the output of mixer 7. During this stage, any solid SiC particles in the original alloy are also mixed continually with liquid phase 4 in mixer 7 to form an integral part of suspension 8 with no risk of the particles being segregated.

Suspension 8 is cast, for example, in an ingot mold 10 to produce an ingot 11 consisting of the original metal alloy, and possibly also containing dispersed SiC particles, but which, due to being cast in semiliquid form, presents an entirely different crystal structure. In pig 1 form, for example, a UNI 3600 alloy presents a dendritic structure as shown in Fig.3, whereas, when rheocast (i.e. cast in semiliquid form through mixer 7) and solidified, the same alloy presents a globular structure as shown in Fig.4.

Ingot 11 is then divided, e.g. cut mechanically using known means, such as a circular saw, into a number of smaller ingots 12, each, including the feedhead and channels, roughly equal to the weight of the component for casting, and which are fed, in stainless steel containers 13 (Fig.2), into an electric resistance furnace 14, preferably specially designed and equipped with automatic robot handling devices 15, where they are heated (for 50-60 minutes) to a temperature within the solidification range of the initial metal alloy. The rheocast globular-structure alloy of ingots 12 (with or without uniformly dispersed SiC particles) thus assumes a semiliquid state having, in the example shown, a liquid phase percentage of roughly 50% by volume, i.e. substantially the same as at the semiliquid casting stage through mixer 7.

When cast through mixer 7, however, the semiliquid alloy, by virtue of mixer 7, presents at most a viscosity of a few P, whereas, in ingot 12 form, by appropriately selecting the chemical composition and the heating temperature within the solidification range of the initial alloy (roughly 580 °C for aluminium alloys), the same semiliquid alloy, but with a globular structure and heated to said temperature within the solidification range of the initial alloy, has been found to present substantially pseudoplastic rheologic characteristics and a viscosity at rest of about 10^7 P. At the output of furnace 14, the alloy of ingots 12 therefore presents a pasty, pudding-like consistency preventing the segregation of any solid ceramic particles, which thus remain uniformly dispersed in the alloy, and enabling ingots 12 to maintain their shape.

Ingots 12 processed as described above are then fed one at a time on to a known die casting machine 18 (not described in detail) fitted with the same molds normally used for liquid alloys, with the exception of the gates, the thickness of which is increased from 0.8:1 mm to 2:2.5 mm to assist throughput of the semiliquid alloy. The semiliquid ingot 12 is fed into a known injection chamber 20 on machine 18, where it is subjected by a piston 21 to a predetermined mechanical pressure, equal to that usually employed for die casting liquid alloys, e.g. 650 Kg/cm^2, and injected into a mold 22 where the alloy solidifies to produce a finished casting 25 consisting, for example, of an internal combustion engine component, such as an injection manifold.

By virtue of the semiliquid form in which it is fed into chamber 20, however, the alloy, as compared with a liquid alloy of the same composition, presents a much higher viscosity and, therefore, a very low Reynolds number, thus enabling injection under laminar flow conditions, as opposed to turbulent flow conditions typical of known liquid alloy die casting processes. The high viscosity at rest combined with laminar-flow injection of the alloy provides, on the one hand, for preventing the inclusion of air bubbles and the formation of blowholes in the finished casting, and, on the other, for preventing the segregation of any solid ceramic particles contained in the semiliquid alloy fed on to machine 18, which particles therefore remain uniformly dispersed both in the semiliquid alloy injected into mold 22 and in the finished casting 25. Nor is the injection stage in any way hampered by the high viscosity at rest of the semiliquid globular alloy, which, being pseudoplastic, reduces its viscosity, when subjected to pressure by piston 21, to a P value of a few tens, compatible with low energy consumption of machine 18.

Claims

1. A process for producing die castings, in particular, light alloy internal combustion engine components, characterized by the fact that it comprises stages consisting in:
   - melting a metal alloy until it is fully liquid;
   - casting said metal alloy in semiliquid form by feeding it, as it solidifies and under laminar flow conditions, through a static mixer for mixing the liquid alloy uniformly with a solid phase, which separates from the liquid alloy to produce a temporary stable solid-liquid suspension at the output of the mixer;
   - solidifying said solid-liquid suspension into rheocast ingots wherein the metal alloy presents a globular micrographic structure;
   - dividing said rheocast ingots into a number of ingots of predetermined weight;
   - heating said ingots to a temperature within the solidification range of said metal alloy, to convert the globular-structure metal alloy into paste form;
   - feeding said ingots, one at a time, into the injection chamber of a die casting machine; and
   - injecting said globular-structure alloy, heated to a temperature within the solidification range of the alloy, into a mold.

2. A process as claimed in Claim 1, characterized by the fact that said ingots are produced by mechanically cutting said rheocast ingots, and each present the same weight as the component for casting.

3. A process as claimed in Claim 1 or 2, characterized by the fact that said ingots are fed, inside respective stainless steel containers, into a preheating furnace in which they are heated to said temperature within the solidification range of the metal alloy.

4. A process as claimed in any one of the foregoing Claims, characterized by the fact that said temperature within the solidification of said alloy and the chemical composition of said alloy are so selected that said globular-structure alloy heated to a temperature within the solidification range of the alloy assumes substantially pseudoplastic rheologic characteristics and a viscosity at rest of about 10^7 P.

5. A process as claimed in Claim 4, characterized by the fact that, during said injection stage, said metal alloy comprises a solid phase and a liquid phase; said solid phase being equal to at least 50% by volume.

6. A process as claimed in any one of the foregoing Claims, characterized by the fact that said melting stage consists in melting pigs of aluminium alloy containing a predetermined percentage of a finely dispersed ceramic material phase; and is conducted in a pot furnace equipped with mixing means.

7. A process as claimed in Claim 6, characterized by the fact that said ceramic phase consists of silicon carbide particles.

8. A process for die casting aluminium alloy, characterized by the fact that it consists in heating an ingot, produced by casting said alloy in semiliquid form to produce a globular micrographic structure of the alloy, to a temperature within the solidification range of the alloy and such as to reduce the alloy to a highly viscous, semiliquid form; and in subsequently exerting mechanical pressure on the ingot.

9. A process as claimed in Claim 8, characterized by the fact that it employs molds having a gate at least 100% larger than normal size.

10. A process as claimed in Claim 8 or 9, characterized by the fact that it employs an aluminium alloy containing a uniformly dispersed ceramic material phase.

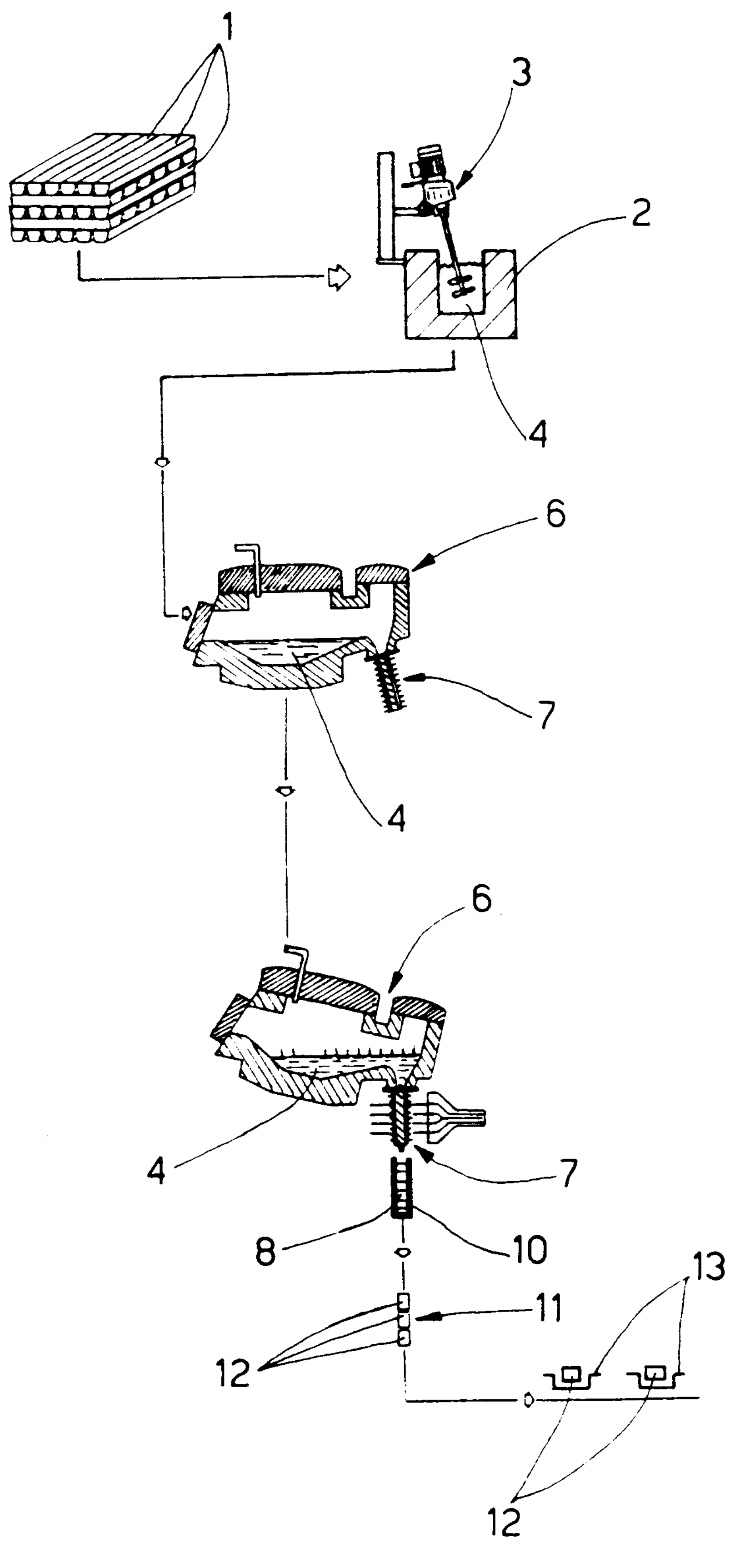

Fig.1

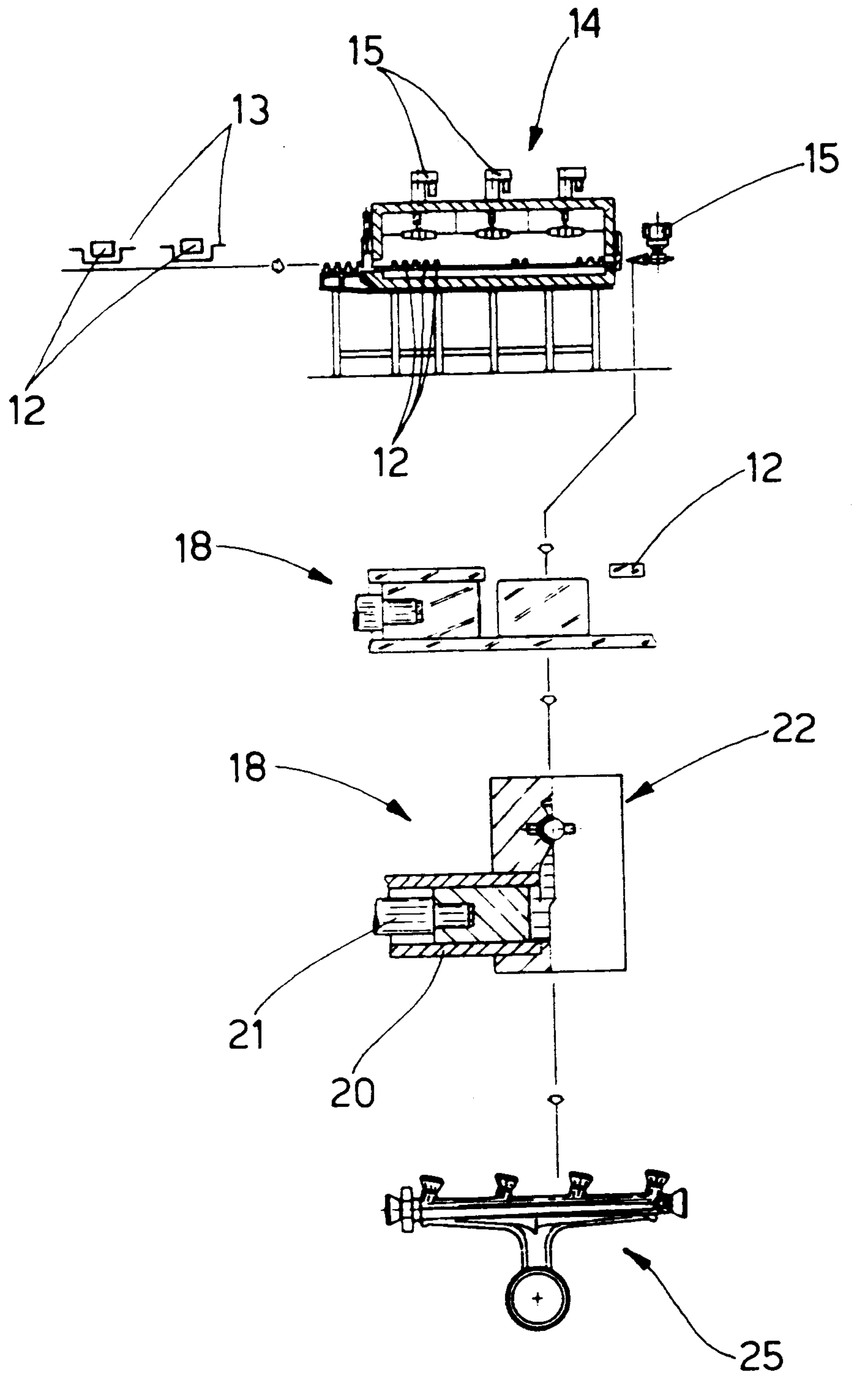

Fig. 2

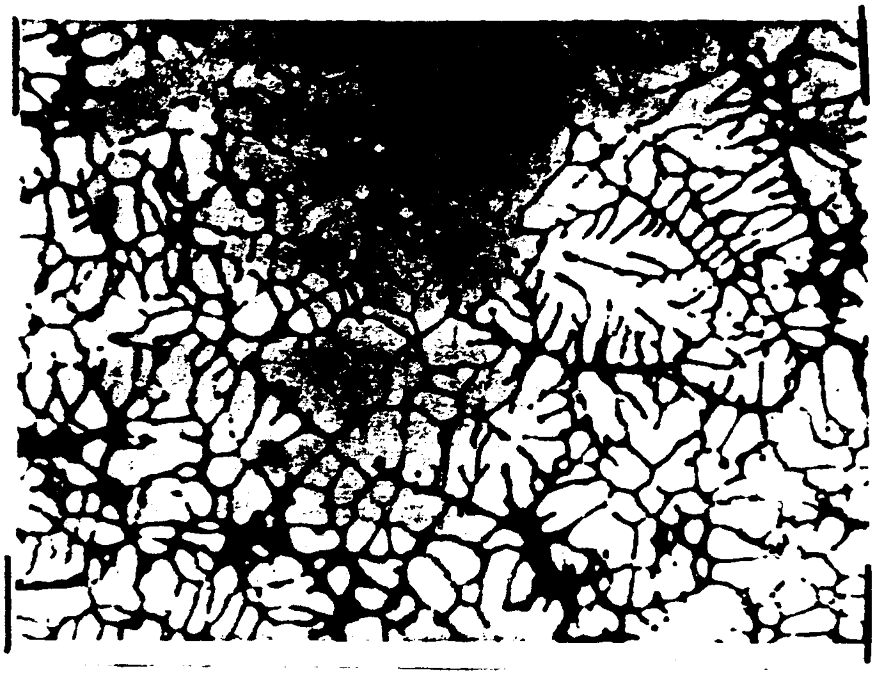

Fig.3

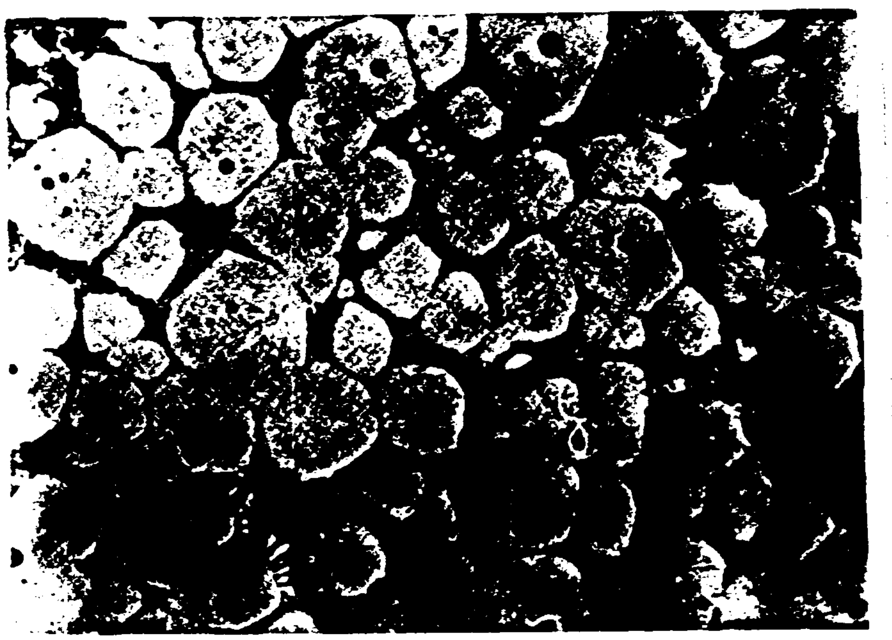

Fig.4

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EUROPEAN SEARCH REPORT

Application Number

EP 92 10 6005

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	VDI ZEITSCHRIFT vol. 133, no. 3, March 1991, DUESSELDORF WOLFGANG SCHNEIDER: 'Formgiessverfahren für innovative Aluminiumgussteile' p. 127-128, 131-133 * the whole document * ---	1,2,4,5, 8,10	B22D17/00 C22C1/00
X	MéMOIRES ET ETUDES SCIENTIFIQUES DE LA REVUE DE MéTALLURGIE vol. 80, no. 7/8, August 1983, PARIS pages 355 - 365; C. MILLIERE ET AL.: 'Structure, propriétés et mise en forme des alliages brassés à l'état semi-solide (suite)' * the whole document * ---	1,2,4-8, 10	
Y	GB-A-2 112 676 (OLIN CORPORATION) * abstract; figure 1 * ---	1,2,4-8, 10	
O,Y	METALLURGICAL TRANSACTIONS B vol. 22B, no. 3, June 1991, WARRENDALE, PA, US pages 269 - 293; MERTON C. FLEMINGS: 'Behavior of Metal Alloys in the Semisolid State' * figures 32,33,36,39 * & EDWARD CAMPBELL MEMORIAL LECTURE HELD IN 1990, ASM INTERNATIONAL -----	1,2,4-8, 10	TECHNICAL FIELDS SEARCHED (Int. Cl.5) B22D C22C

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	20 AUGUST 1992	HODIAMONT S.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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