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**GB 581244**
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## (54) Process for the production of castings solidifying in a required orientation

(57) To simplify the production of castings solidifying with a required orientation in a vacuum or a protective gas atmosphere, more particularly in order to avoid heating or re-heating the mould in a vacuum casting system, the mould shell (1) is preheated, removed from its heating system and — mounted on a cooling system (2) — introduced into the vacuum casting system through a lock for pouring of the melt. The melt is so superheated that its superheating enthalpy above liquidus temperature at least heats the mould cavity to above that temperature after casting. Control of the cooling conditions of the mould, e.g. by upwardly increasing layer thicknesses of the shell (1) and/or its surrounding insulation (11), compel the columnar crystals to grow in the required direction.

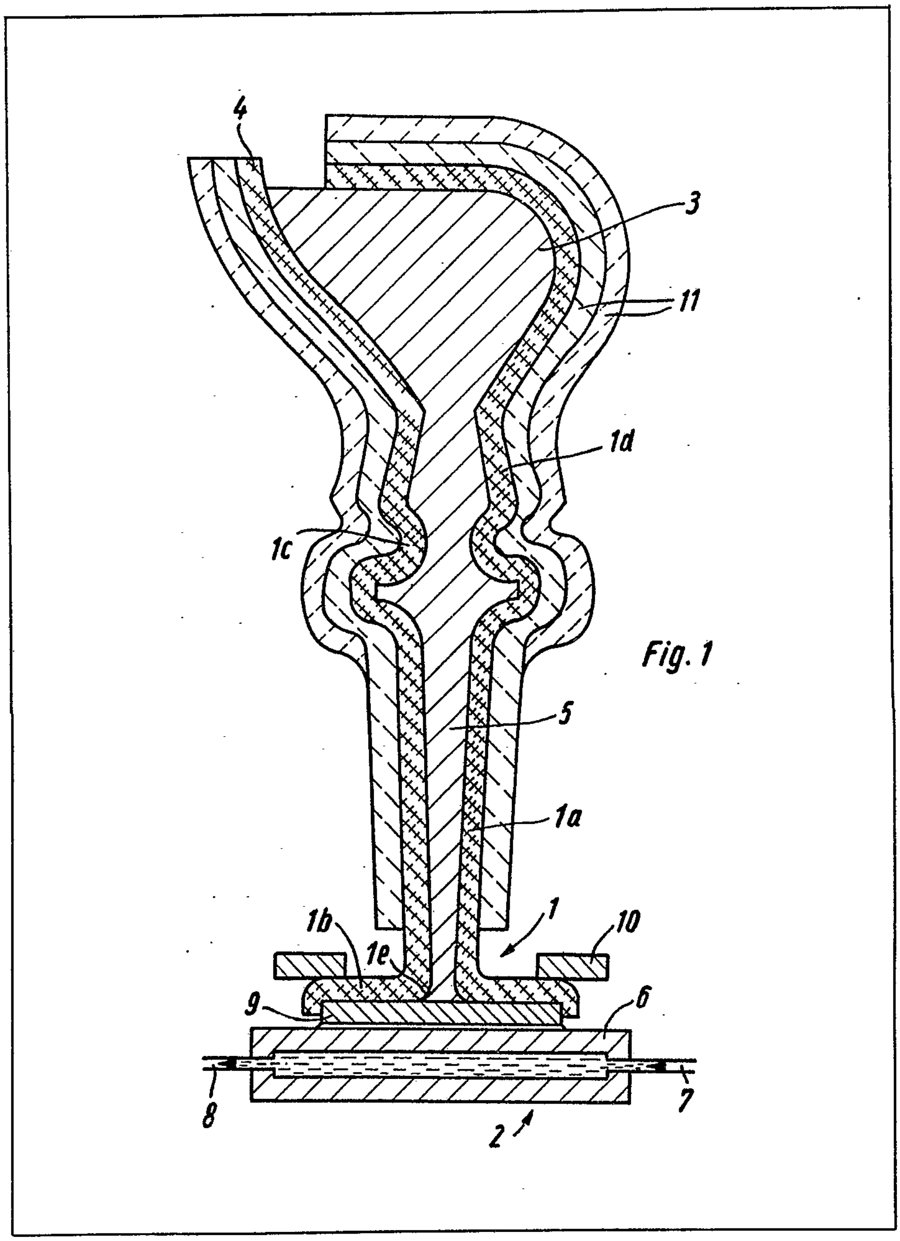

Fig. 1

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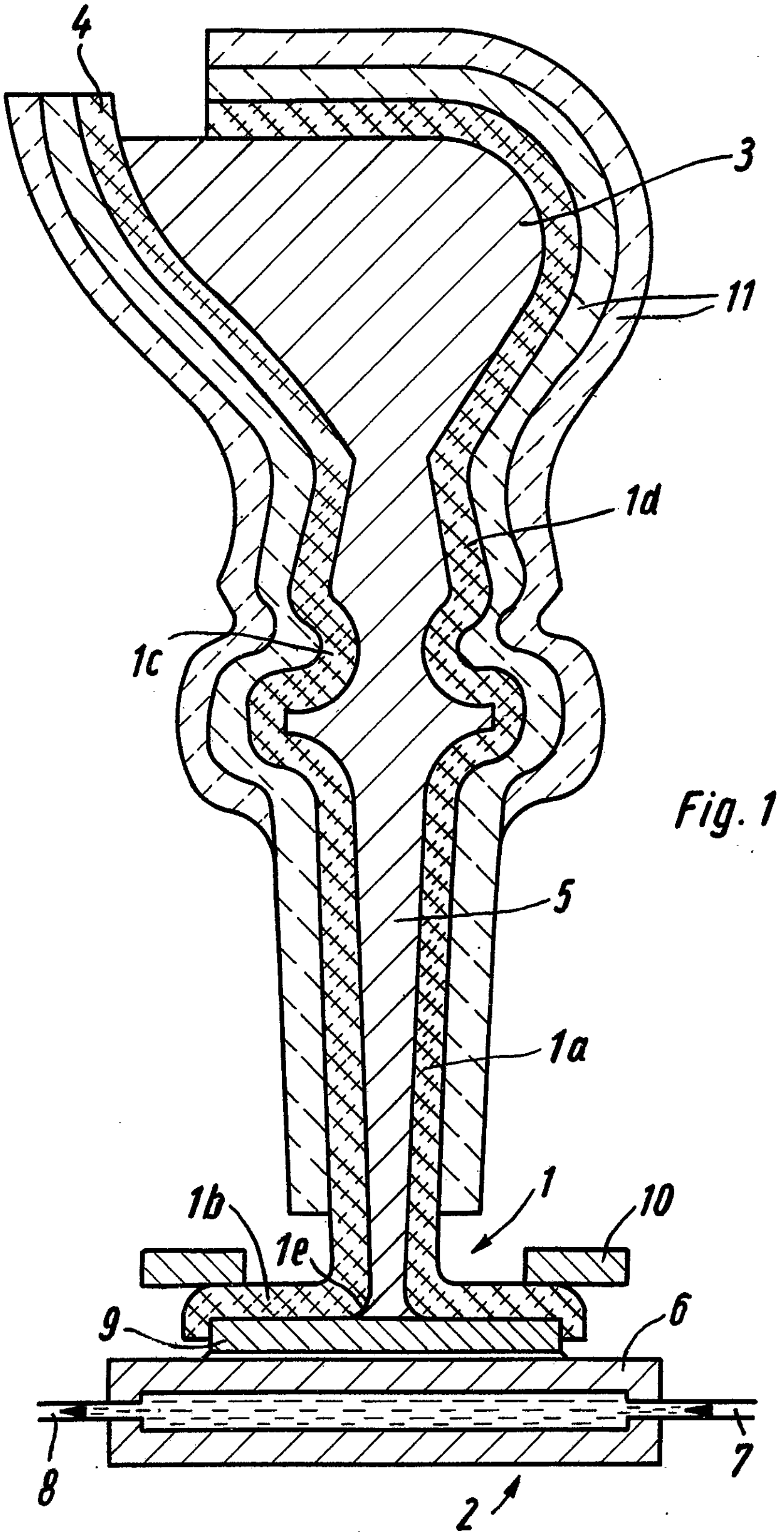

Fig. 1

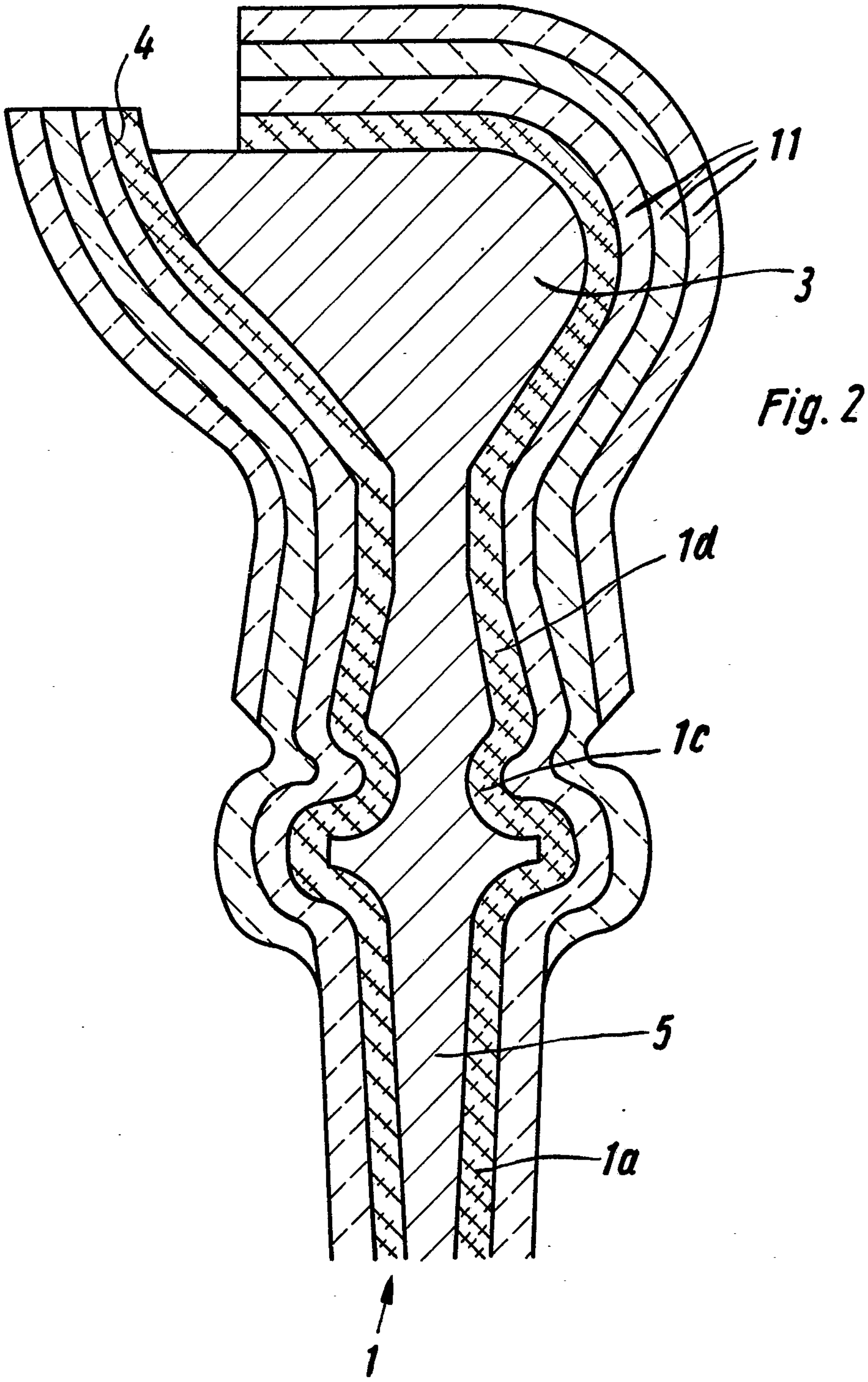

Fig. 2

SPECIFICATION

## Process for the production of castings solidifying in a required orientation

This invention relates to a process for the production of castings with a required crystal orientation, by vacuum or protective gas casting in precision casting moulds, a superheated melt being poured into a preheated ceramic mould comprising a ceramic part closed at a bottom end by a plate made from a material which is a good thermal conductor and which has a coolant flowing through it.

It is well known that certain properties (e.g. good mechanical properties at high-temperature) of castings, e.g. gas turbine blades, can be greatly improved if the castings consist of material which has solidified in a required crystal orientation. In such castings, the crystals which grow during solidification have their axes lying in a preferential direction, e.g. the longitudinal direction of the turbine blade, and this is achieved by intentional and controlled cooling of the melt after casting. The prior-art processes used for this purpose, to produce a flat solidification front extending normally to the required direction of crystal growth as far as possible, are time-consuming and expensive, since they require that the mould filled with the melt should be heated in a vacuum or protective inert gas atmosphere and such heating has to be staggered with the progress of the solidification front. These processes therefore require considerable capital investment in heating equipment and in the means for providing the vacuum or protective gas atmosphere, the heating equipment having to be movable relative to the mould or to give an output which can be varied over the height of the mould.

A known process for the production of castings having the required crystal orientation and prior art apparatus used for the process are described, for example, in German Offenlegungsschrift 2230 317, which shows an apparatus in which a heating system displaceable relative to the mould is provided in a vacuum vessel. The mould conventionally consists of a ceramic shell without a base and fitted on a plate which is formed of a material which is a good thermal conductor and which is arranged to have a coolant flowing through it.

An object of the present invention is to simplify the prior-art processes, more particularly to avoid heating the mould in a vacuum or protective inert gas vessel and so to dispense with the heating systems required for that purpose, together with the associated transportation systems by means of which the heating systems are moved in relation to the mould.

Accordingly the present invention provides a process for the production of a casting having a desired crystal orientation, by vacuum or protective gas casting, in which superheated melt is poured into a preheated ceramic mould having a ceramic part closed at a bottom end by a plate made from a material which is a good thermal conductor and which has a coolant flowing through it; wherein the ceramic mould part is surrounded by insulating material and is preheated and then removed from the means used to heat it and mounted on the plate which is disposed in a vacuum container, the container is then evacuated and optionally filled with inert gas, and the superheated melt is then poured into the mould, without the mould being preheated further; the superheating of the melt, and the preheating and dimensions of the ceramic mould part and its insulation being so chosen in relation to one another that the incoming melt heats at least the ceramic mould part wall enclosing the mould cavity to a temperature above the melt liquidus temperature; and the cooling conditions being determined by varying thickness of the mould wall and/or of its surrounding insulating material over its height, so that the mould wall temperature at any level in the solidification zone of the melt parallel to the surface of the cooling plate is at least equal to the local temperature of the melt.

In this specification the expression superheated melt is used to mean a melt which has been heated to a temperature above its liquidus temperature.

The process eliminates the need for heating the mould in the vacuum vessel either before or after casting, since the mould cavity is initially heated above and at least initially kept at the solidification temperature by the superheated melt. The cooling conditions governed by different thicknesses of the shell and/or layers of insulation ensure that the solidification front progresses in the required direction.

If necessary, the cooling conditions can be so determined, e.g. by appropriate shape and thickness of the layers of insulation in various zones of the mould height, that the finish of the required orientation casting remote from the plate is followed by a random-orientation zone in the casting. Such a zone may, for example, form the root of a turbine blade which has solidified with a required crystal orientation.

To prevent impurities from passing into the melt from the coolant plate, an intermediate plate of the same material as the intended casting may be placed on the coolant plate in thermally conductive contact with it.

Apart from varying the thickness of the layers of the ceramic shell and/or the insulation surrounding the same, the cooling conditions can readily be varied by changing the thickness of the cooling plate and/or of the intermediate plate.

The casting, which shrinks on solidification, can be prevented from tearing away from the intermediate plate when it is used if the mould cavity is widened with respect to the intermediate plate at the bottom end, e.g. by rounding the mould cavity edges.

In order to promote a fuller understanding of the above and other aspects of the present invention, an embodiment will now be described, by way of example only, with reference to the accompanying drawings in which Figure 1 is a longitudinal section of a ceramic moulding shell, which is secured on a plate through which a coolant flows, the shell being arranged to experience cooling conditions which vary over its height.

Figure 2 is a variant of the top part of the shell shown in Figure 1.

The embodiment shown in the drawings is based on the manufacture of a directionally orientated crystal structure gas turbine blade from the nickel-based alloy IN 738 LC; this alloy having the following known composition (in % by weight): C 0.11; Cr 16.0; Co 8.5; Mo 1.7; W 2.6; Ta 1.7; Nb 0.9; Al 3.5; Ti 3.5; Zr 0.05; B 0.01 and Ni remainder.

A ceramic moulding shell 1 (Figure 1) is built up from individual layers on a 'lost wax' pattern in the conventional manner for investment casting moulds. In this process, the pattern is repeatedly immersed into a fused mullite dip, to which an ethyl silicate binder has been added. Each layer is then sanded with granular fused mullite. The dipping and sanding operations are continued until the shell thickness is about 10 mm, this requiring 10 dips for example. Alternatively, other shell thicknesses can be used, more particularly a shell with wall thicknesses varying over the height in order to influence the cooling conditions after casting; for example a wall or shell thickness of 10 mm may be provided at the bottom, i.e. near the bottom plate which is cooled, and which will be described hereinafter, and then this thickness increases uniformly in the upward direction as far as a gate 3, for example to a thickness of 20 mm. Critical zones of the shell 1 such as that at the transition 1c from the body 1a to the root 1d of a blade to be cast, may also be reinforced by means of an aluminium oxide cement and a silicate binder.

At the bottom end of the mould, the part 1a of the shell 1 forming the body of the blade to be cast merges into a flange-like extension 1b, while the part of the shell 1d which forms the blade root is provided above. A gate 3 is provided above the portion 1d and also acts as a feeder and heat store. On the left-hand side of Figures 1 and 2 it is formed as a spout 4 to receive the molten metal to be cast as at 5.

The transition 1e of the mould cavity from the zone 1a of the blade body to the flange 1b by means of which the shell 1 is fitted on to the cooled plate, is arcuate, so that there is a small widening of the mould cavity at the bottom end. This is intended to prevent the cast material from lifting or tearing away from the plate, during the shrinkage of such material on solidification, since it would impair the heat transfer to the plate.

The cooled bottom plate indicated at 2, which is shown purely in diagrammatic form and which, for performance of the process, is fitted in a vacuum casting system, comprises a hollow member 6 of low-alloy carbon steel, through which cooling water is caused to flow. The hollow member 6 is connected to the cooling water supply via conduits 7 and 8, which are shown simply diagrammatically and which are taken out through the vacuum lock of the vacuum casting vessel (not shown). An intermediate plate 9 of a material of the same nature as the material to be cast, i.e. In 738, is soldered on to the hollow member 6 by means of a commercial nickel-based solder, which contains at least chromium and boron. The dimensions of the flange 1b of the shell 1 are adapted to the size of the intermediate plate 9. Shell 1 is thus specifically held and centred on the intermediate plate 9. The plate ensures that impurities in the melt which might be caused by dissolving material of the hollow member 6 are prevented. The shell 1 is pressed on to the intermediate plate 9 by means of a clamping system, of which the drawing shows only the limbs 10 bearing on the flange 1b on either side of the shell 1.

To perform the process according to this embodiment of the invention, insulating material 11 is wound around the shell 1, this material comprising an approximately 12 mm thick ceramic felt of $Al_2O_3$ fibres. As will be seen in Figure 1, the insulation 11 does not extend as far as the flange 1b of the shell 1, but terminates some distance thereabove. First one, then two, and in some cases finally three layers of insulation 11 are provided progressively in the upward direction (Figure 2). These layers 11 are retained by nickel wire wound around them. The reason for the increase in the thickness of the layers of insulation 11 in the upward direction, like the changes in the shell wall thickness which may be provided as already stated, is to ensure that the mould cavity cools as uniformly progressively as possible in the upward direction through each level so that the melt cools in the same way to give an upwardly directed columnar crystal growth.

The height of the shell 1 at which the insulation 11 or another layer thereof must start is determined experimentally, it being possible to check that the required crystal growth direction is maintained, i.e. that the solidification front really does progress perpendicularly to the axis of the mould cavity, by reference to the crystals that have already grown.

Figure 1 shows the insulation 11 of a shell 1 in which the blade root 1d and the gate 3 solidify in random-orientation crystals, because the insulation 11 has the same thickness throughout the height of the shell and there is therefore no preferential direction for the progress of solidification in those areas.

In the mould shown in Figure 2, a preferential direction of this kind is obtained, at least for the area 1d of the blade root, by providing an additional layer of insulation 11 around the zone 1d and the gate 3. At least the blade root 1d therefore will also solidify with the required orientation in the mould shown in Figure 2.

In conclusion, the performance of the process embodying the invention will be outlined in brief detail:

The shell 1 together with its insulation 11 is heated to a temperature of about 1200°C in a furnace, e.g. a muffle furnace. Independently of this, the casting material is melted in a vacuum casting system at a pressure of about $5 \times 10^{4}$ mbar in a commercial crucible consisting of Si-Al-Oxide. The melt is superheated until its temperature is at least 200°C above the liquidus temperature, the liquidus temperature in this example having been found by measurement to be 1325°C, the vacuum being replaced by a protective inert gas atmosphere consisting, for example, of argon at a pressure of about 100—250 mbar. Even at these high temperatures, the protective gas substantially prevents any evaporation of melt into the vacuum and any reactions between the melt and the material of the crucible and shell 1.

Once the shell 1 and the melt have reached the required temperatures — in the example described the melt was heated, for example, to a temperature of 1650°C — the hot shell is mounted on the cooling system 2 in a vacuum lock and is held by the clamping system; the matched square shape of the intermediate plate 9 and the flange 1b fixes the shell 1 — relative to the melt-containing crucible in the vacuum furnace, in the correct position, suitable marking being provided to ensure that the shell gate 4 points in the correct direction of the intermediate plate 9.

Once the shell 1 has been mounted on the cooling system 2 and the flow of coolant has been started, the lock is closed, evacuated, and the cooling system 2 together with the shell 1 is placed in the protective gas atmosphere of the vacuum casting system, the required protective gas pressure being maintained as necessary by the introduction of additional protective gas. Once the mould is in the vacuum caster the superheated melt is immediately poured.

During casting, the superheated melt heats at least the cavity of the ceramic shell 1 to above the liquidus temperature as required by the invention. At the same time, however, the oriented columnar crystal growth starts from the cooling system 2.

After casting, the mould filled with the melt can be removed through the lock either directly or else after some time during which solidification has already advanced to some extent, and then be exposed to air for further cooling.

When the casting 5 has completely solidified, the shell 1 is removed or destroyed and the casting 5 is separated from the intermediate plate 9 of the cooling system 2, e.g. it is simply broken away, because the casting 5 usually does not adhere very firmly to the intermediate plate 9.

## CLAIMS

1. A process for the production of a casting having a desired crystal orientation, by vacuum or protective gas casting, in which superheated melt is poured into a preheated ceramic mould having a ceramic part closed at a bottom end by a plate made from a material which is a good thermal conductor and which has a coolant flowing through it; wherein the ceramic mould part is surrounded by insulating material and is preheated and then removed from the means used to heat it and mounted on the plate which is disposed in a vacuum container, the container is then evacuated and optionally filled with inert gas, and the superheated melt is then poured into the mould, without the mould being preheated further; the superheating of the melt, and the preheating and dimensions of the ceramic mould part and its insulation being so chosen in relation to one another that the incoming melt heats at least the ceramic mould part wall enclosing the mould cavity to a temperature above the melt liquidus temperature; and the cooling conditions being determined by varying thickness of the mould wall and/or of its surrounding insulating material over its height, so that the mould wall temperature at any level in the solidification zone of the melt parallel to the surface of the cooling plate is at least equal to the local temperature of the melt.

2. A process as claimed in Claim 1, in which the cooling conditions for the ceramic mould part are determined so that the finish remote from the cooling plate of the oriented casting required is followed by a random-orientation casting zone.

3. A process as claimed in Claim 1 or Claim 2, in which the mould is preheated to a temperature below the melting temperature of the material to be cast and the melt is superheated by at least 200°C.

4. A process as claimed in any one of the Claims 1 to 3, in which an intermediate plate of the same material as the melt is placed over the plate in thermally conductive contact therewith, before the melt is poured.

5. A process as claimed in any one of the Claims 1 to 4, in which the thicknesses of the plate is varied in order to vary the cooling conditions.

6. A process as claimed in Claim 5 as dependent on Claim 4, in which the thickness of the intermediate plate is varied in order to vary the cooling conditions.

7. A process as claimed in any one of Claims 1 to 6, in which characterised in that the bottom end of the mould cavity widens out in the direction of the plate.

8. A process for the production of a casting substantially as herein described with reference to the accompanying drawings.

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