METHOD OF HEALING SURFACE-CONNECTED DEFECTS IN CASTINGS

A method of healing surface-connected defects in castings by means of hot-isostatic pressing in a high-pressure furnace with a pressure medium in the form of a gas, wherein said casting is enclosed in an enclosure impenetrable to said pressure medium. The defective casting (10) is coated with a layer of a powdered material (16) which essentially retains its crystalline state in contact with both the casting and the glass enclosure in connection with the hot-isostatic pressing, whereupon a powdered glass or a material (15) forming glass upon heating is applied around the body. Then the coated casting and the glass powder are heated such that a dense coherent glass enclosure is formed which surrounds the casting before an isostatic pressure is applied outside said glass enclosure to act on the casting and remove defects present in the casting. After the hot-isostatic pressing, the powdered layer and the glass enclosure are removed from the casting which has been freed from surface-connected defects.
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Method of healing surface-connected defects in castings

TECHNICAL FIELD

5 The invention relates to a method of healing defects in castings by hot-isostatic pressing.

BACKGROUND ART

10 It is known that defects such as cracks, pores and other voids in castings can be corrected by hot-isostatic pressing. Healing by means of hot-isostatic pressing has particular importance in castings of expensive materials such as so-called superalloys on cobalt or nickel base.

15 Since castings of this type are usually used in applications involving high performance requirements, high demands are placed on freedom from defects, and repairing castings by methods accepted for simpler materials and applications, such as repairing by welding, cannot be accepted, and therefore the number of rejections as a result of casting defects would be considerable unless the defects were corrected by hot-isostatic pressing.

The hot-isostatic pressing is carried out in high-pressure furnaces with an inert gas as pressure medium and normally at high temperature.

Healing of defects by hot-isostatic pressing is not immediately applicable to surface defects such as surface-connected cracks and pores since these are not compressed by the applied isostatic pressure. Castings with these types of defects must still be rejected. These surface-connected defects are a particularly great problem in the case of advanced materials which are difficult to cast, such as superalloys on nickel and cobalt base, as well as for titanium alloys. In particular, these surface-connected defects are of great technical and economic importance for
castings of superalloys with applications such as turbine housings, turbine wheels, and turbine blades.

From Swedish patent specification SE-B-435 243, a method is known by which castings are formed by casting in a mould whereupon the casting with the surrounding mould is surrounded by a gas-tight glass layer, is heated and compacted isostatically to compress pores and cracks, formed during the casting, into a dense, pore-free casting. This method presupposes that the casting mould used remains intact during cooling, application of the glass layer and reheating to the pressing temperature. Usually, however, the casting mould cracks during this treatment, causing the applied glass layer to penetrate into surface-connected cracks and pores with the result that these cannot be caused to heal during the treatment with hot-isostatic pressing.

One object of this invention is to bring about a method for healing castings with surface-connected defects by means of hot-isostatic pressing by protecting the surface-connected defects from penetration by the pressure medium, the enclosure or other material which prevent healing of the defects mentioned.

SUMMARY OF THE INVENTION

The present invention relates to a method of healing surface-connected defects in castings by means of hot-isostatic pressing in which the defective casting is enclosed in an enclosure which is impenetrable to the pressure medium, before the casting is hot-isostatically pressed.

According to the invention, the casting is first coated with one or more layers of powdered material. This powder layer, the blocking layer, blocks surface-connected cracks and pores and prevents the enclosure material, preferably a glass, from penetrating into the surface-connected defects.
with the isostatic pressing suitably consist of materials which maintain their crystalline state in contact with both the glass and the castings at the pressing temperature. Examples of suitable materials are intermediate phases in the system $\text{Al}_2\text{O}_3$-$\text{SiO}_2$ of which mullite $3\text{Al}_2\text{O}_3$·$2\text{SiO}_2$, sillimanite $\text{Al}_2\text{O}_3$·$\text{SiO}_2$ and kyanite $\text{Al}_2\text{O}_3$·$\text{SiO}_2$ (a high-pressure modification of sillimanite) can be mentioned. The blocking layer may also contain a powdered additive consisting of one or more of substances such as aluminium oxide, zirconium oxide, mullite, titanium boride, silicon nitride, silicon carbide, titanium nitride, boron nitride or a high-melting glass which does not react, or only insignificantly reacts, with the material in the blocking layer, such that the blocking layer in all essentials maintains its crystalline state. As examples of high-melting glasses which may be used can be mentioned quartz glass and a glass containing 96.7 per cent by weight $\text{SiO}_2$, 2.9 per cent by weight $\text{B}_2\text{O}_3$ and 0.4 per cent by weight $\text{Al}_2\text{O}_3$ (Vycor®). The additive can be included in combination with intermediate phases in the system $\text{Al}_2\text{O}_3$-$\text{SiO}_2$ such as mullite $3\text{Al}_2\text{O}_3$·$2\text{SiO}_2$, sillimanite $\text{Al}_2\text{O}_3$·$\text{SiO}_2$ and kyanite $\text{Al}_2\text{O}_3$·$\text{SiO}_2$ in contents up to 60 %, preferably up to at most 30 % of the total dry weight of all constituents in the blocking layer. To ensure that the suspension does not penetrate into the surface-connected pores during the dipping, these can first be sealed by organic materials, for example pore-sealing compounds of anaerobically curing organic materials, such as methacrylates, before the blocking layer is applied, these organic materials being driven off before the enclosure in glass.

In one embodiment, the blocking layer is supplemented by an internal layer which, in addition to preventing glass from penetrating into the surface-connected defects or reacting with the castings, also acts as a release agent. This complementary release layer is arranged nearest the body to be easily removed from the body, after the hot-isostatic pressing, together with the externally applied blocking layer and the glass enclosure. The release layer preferably
consists of boron nitride. Boron nitride has insignificant or no tendency to react with the castings. Boron nitride in commercially available qualities are well suited for this purpose. As an alternative to boron nitride, it is possible, depending on the casting, to use other substances with layered structure such as graphite and molybdenum disulphide and also boron nitride mixed with silicon nitride, silicon carbide, titanium nitride, titanium boride, etc.

The particle size of the powder in the blocking layer is suitably chosen to be between 0.1 and 200 μm, preferably to be less than 150 μm, and the material is applied to form a layer with a thickness of between 0.1 and 3 mm, preferably with a thickness of between 0.3 and 0.6 mm.

For the complementary release layer, which is applied inside the intermediate layer, the particle size is suitably chosen to be between 0.1 and 100 μm, preferably to be less than 45 μm. The layer is suitably applied to a thickness of between 0.1 and 2 mm, preferably to a thickness of between 0.2 and 0.6 mm.

Both the intermediate layer and the complementary release layer can be applied to the casting by means of dipping into a suspension of the powdered materials which are included in the respective layers, by spraying or in some other way. A suspension is suitably prepared by addition of a solvent such as a cyclohexane, a ketone, ethanol or another alcohol, in a content of 80 to 92 parts by volume to the powdered material. Suitable dispersion and suspension-promoting agents as well as other surface-active agents can be added to ensure that an essentially fully covering and even coating of the suspension remains on the casting. The application is followed by a drying operation when the solvent is driven off and a covering even layer of the desired thickness is obtained. The layers can be applied by dipping once or twice, with or without intermediate drying, in the respective suspension to obtain the desired layer thickness.
It has proved that in many cases a layer, applied by repeated dipping into a layer with a thickness of between 0.6 and 1.2 mm, gives an excellent result. This layer consists of 30 to 80, preferably 50, per cent by volume of boron nitride, with a specific surface of 6 m²/g mixed with 70 to 20, preferably 50, per cent by weight mullite with a grain size smaller than 45 μm. The powdered materials are suspended in isopropanol into a content of 15 to 25 per cent by volume of solid constituents. To this mixture there is added a binder in the form of a polyacrylate into a content of about 5 per cent by weight. The casting is dipped while being turned around between the dipping operations such that the suspension is applied onto all the surfaces, whereupon it is allowed to dry. This dipping operation is repeated 2 to 4 times such that a layer with a total thickness of about 1 mm is obtained.

To ensure that the suspension does not penetrate into the surface-connected pores during the dipping, these can first be sealed by organic materials. This is done by adding polyethylene glycol dimethacrylate to the casting, for example by dipping. The polyethylene glycol dimethacrylate is thereby sucked into the pores and hardens. The external polyethylene glycol dimethacrylate is rinsed away whereupon the casting is dipped into the suspension in the manner described above.

The castings, which may have a weight of 50 kg or more, are placed on ceramic supports, for example of solid silicon nitride or boron nitride, in graphite crucibles. After drying, the object is covered with a powdered glass or a material which forms glass upon heating. Then the body and the glass powder are heated, usually under vacuum, to a temperature such that the glass or the glass-forming material forms a dense, coherent enclosure around the defective casting. During the heating, the organic constituents included in the applied powder layer, as well as any polyethylene glycol dimethacrylate used for pore sealing,
are evaporated in gaseous form before the glass particles sinter together into a gas-tight enclosure.

In a particularly preferred embodiment of the invention, a glass is used which is easily removed by means of simple chemical methods such as dissolution in hot water or water vapour. This embodiment is especially advantageous and of economic importance in castings of an intricate shape. Suitable glasses comprise 30 to 70 per cent by weight boron oxide, up to 2.5 per cent by weight aluminium oxide, the balance being silicon oxide. For example, a glass is used with a composition of 60 per cent by weight boron oxide, 2 per cent by weight aluminium oxide and 38 per cent by weight silicon oxide. Preferably, a glass is used with the composition 67 per cent by weight silicon oxide and 33 per cent by weight boron oxide. The use of this glass, in combination with the single layer mentioned above, gives an optimal system for use when healing surface-connected defects in castings in superalloys such as INCONEL 718.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be explained in greater detail in the following with reference to the accompanying drawing.

Figures 1 and 2 show a casting in the form of a turbine wheel with defects, whereas Figure 3 shows the same turbine wheel coated with a release layer, a blocking layer and surrounded by a glass enclosure before hot-isostatic pressing for the purpose of removing defects arising in the casting during the casting operation.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The turbine wheel 10 in Figures 1 and 2 comprises a hub 11, a web 12, an edge 13 and blades 14. The turbine wheel 10 is cast in a nickel-base alloy, for example INCONEL 718, and has casting defects in the form of surface-connected pores
After drying, the coated turbine wheel 10 is covered with an enclosure of glass 15 or a material forming glass upon heating, applied outside the layers. Before the preformed body is compacted by isostatic pressing and sintered, the enclosure 15 is made impenetrable to the pressure medium by heating.

The glass enclosure 15 is produced by arranging the turbine wheel 10 together with glass particles in a graphite crucible 18, which is internally provided with a layer of boron nitride 19. The crucible 18 with its contents is placed in a high-pressure furnace, in which the binders in layers 16 and 17, the acrylates, are driven off in vacuum or flushing nitrogen gas or hydrogen gas at temperatures up to 600°C. Thereafter, the temperature is raised while continuing flushing with nitrogen gas at a pressure of some kPa above atmospheric pressure successively to a temperature of between 1000 and 1200°C such that the glass melts and forms an enclosure 15, impenetrable to the gaseous pressure medium. The flushing is interrupted and argon gas is pumped in to raise the pressure to 100 MPa and the temperature is raised to between 1050 and 1200°C. The furnace is maintained under these conditions for a period of 1 to 4 hours. During treatment of INCONEL 718, the treated casting is maintained at 100 MPa and 1130°C for 2 hours.

The treatment up to 600°C can alternatively be made in a separate furnace which need not be a high-pressure furnace.

During treatment of a compressor housing cast in the titanium alloy Ti-6Al-4V and provided with surface-connected pores and/or cracks, a single layer is applied. This layer consists of 50 per cent by volume boron nitride, with a specific surface of 6 m²/g mixed with 50 per cent by volume quartz glass, crushed down to a grain size smaller than 125 µm. The powder materials are suspended in isopropanol to a content of 12 to 15 per cent by volume solid constituents. To this mixture there is added a binder in the form of a
polyacrylate to a content of about 5 per cent by weight. The compressor housing is dipped while being turned around between the dipping operations such that the suspension is applied onto all the surfaces whereupon it is allowed to dry. This dipping operation is repeated 3 times such that a layer with a total thickness of about 1 mm is obtained.

The compressor housing is placed on a support of solid boron nitride in a graphite crucible and is covered after the drying with a powdered glass of a composition of 65 per cent by weight boron nitride, 1.5 per cent by weight aluminium oxide and 33.5 per cent by weight silicon oxide. Then the crucible with its contents of compressor housing and glass powder is placed in a high-pressure furnace. The furnace is evacuated whereby the binder is driven off under vacuum, while the temperature is raised to 600°C. When the binder has been driven off, the heating continues while flushing with nitrogen gas of a few kPa above atmospheric pressure up to a temperature of 950°C, such that the glass melts and forms a dense, coherent enclosure around the defective compressor housing. The flushing with nitrogen gas is interrupted, the pressure is raised to 100 MPa by pumping in argon and the temperature is raised to 990°C whereupon the compressor housing is treated under these conditions for 2 hours. After cooling, the glass is removed by dissolution in hot water or water vapour, whereupon the compressor housing in a known manner is treated in vacuum at elevated temperature to remove hydrogen gas absorbed in the material.

A turbine part with a surface-connected porosity of INCONEL 718, and where it is desired to ensure that no material from the blocking layer or the glass enclosure penetrates into the open pores, is first dipped into a bath with a low-viscous anaerobically curing polyethyleneglycol dimethacrylate compound, LOCTITE 290. The part is allowed to remain in the bath for about 30 minutes and is then left for 30 minutes to allow the surplus to run off. Then the part is rinsed in hot water, about 60°C. The applied polyethylene-
glycol dimethacrylate seals the surface-connected pores temporarily and prevents the suspension with the blocking layer from penetrating into the pores during the application.

A blocking layer, which prevents the glass enclosure from penetrating into the pores during the hot-isostatic pressing, is applied by dipping the pore-sealing turbine part in a suspension of 50 per cent by volume hexagonal boron nitride, with a specific surface of 6 m²/g, mixed with 50 per cent by volume mullite, with a grain size smaller than 45 μm in isopropanol. The content of the suspension of solid constituents amounts to between 18 and 25 per cent by volume. To this mixture there is added a binder in the form of i-butylnmethacrylate to a content of about 6 per cent by weight.

The turbine part is dipped while being turned between the dipping operations such that the suspension is applied onto all the surfaces, whereupon it is allowed to dry. This dipping operation is repeated 3 times such that a layer with a total thickness of about 1.5 mm is obtained.

The turbine part is placed on a support of solid boron nitride in a graphite crucible and is covered after drying with a powdered glass of a composition of 33 per cent by weight boron oxide and 67 per cent by weight silicon oxide. Then the crucible with its contents of turbine part and glass powder is placed in a high-pressure furnace. The furnace is evacuated whereby the binder is driven off under vacuum while the temperature is raised to 600°C. When the binder and the organic sealing compound have been driven off, the heating continues while flushing with argon of some kPa above atmospheric pressure up to a temperature of 1150°C such that the glass melts and forms a dense coherent enclosure around the defective turbine part. The flushing with argon is interrupted, the pressure is raised to 100 MPa by pumping in argon and the temperature is raised to 1200°C
whereupon the compressor housing is treated under these conditions for 2 hours. After cooling, the glass is removed by means of dissolution in hot water or water vapour.
CLAIMS

1. A method of healing surface-connected defects in castings by means of hot-isostatic pressing in a high-pressure furnace with a pressure medium in the form of a gas, wherein said casting is enclosed in an enclosure of glass impenetrable to said pressure medium, whereby said defective casting is coated with one or more layers (16, 17) of powdered material before being enclosed in a glass enclosure (15) impenetrable to the pressure medium, characterized in that said defective casting (10) is coated with one or more layers of a powdered material (16) which essentially retains its crystalline state in contact with both the casting and the glass enclosure in connection with the hot-isostatic pressing before a powdered glass or a material (15) which forms glass upon heating is applied around the body, whereupon the coated casting and the glass powder are heated such that a dense, coherent glass enclosure is formed to surround the casting before an isostatic pressing is applied outside said glass enclosure to act on the casting and remove defects present in the casting, said layer and glass enclosure being removed from the casting, which is freed from surface-connected defects, after the hot-isostatic pressing.

2. A method according to claim 1, characterized in that a layer (17) in the form of a powdered material is applied in immediate contact with the surface of the casting, said material comprising a material, a release agent, which has no tendency, or insignificant tendency, to react with the casting during the treatment and thereby facilitates the removal of said layer and glass enclosure.

3. A method according to claim 2, characterized in that a layer (17) comprising at least boron nitride is applied to said defective casting before being enclosed and treated by means of hot-isostatic pressing.
4. A method according to any of the preceding claims, characterized in that a layer comprising 30 to 80 per cent by volume of boron nitride and 70 to 20 per cent by volume of powdered mullite is applied to said defective casting, whereby said defective casting is dipped into a suspension of said powdered material in isopropanol with 15 to 25 per cent by volume of solid constituents and to which a binder, in the form of a polyacrylate, is added in a content of 5 per cent by weight, the casting is dipped 2 to 4 times or until a layer of between 0.6 and 1.2 mm is obtained, and after drying the coated casting is enclosed and treated by means of hot-isostatic pressing.

5. A method according to any of the preceding claims, characterized in that said defective casting coated with said layer is enclosed in a glass-forming powder comprising 30 to 70 per cent by weight boron oxide, up to 2.5 per cent by weight aluminium oxide, the balance being silicon oxide, whereby said glass enclosure after the hot-isostatic treatment is removed by dissolution in hot water or water vapour.

6. A method according to any of the preceding claims, characterized in that the surface-connected pores in said casting are first sealed by means of a pore-sealing organic material which fills up the pores and prevents the material included in the blocking or release layer from penetrating into the pores.
**INTERNATIONAL SEARCH REPORT**

**International application No.**

PCT/SE 93/00180

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**A. CLASSIFICATION OF SUBJECT MATTER**

**IPC5:** B22D 27/09, C22F 1/00  
According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

**IPC5:** B22D, C22F  
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE, DK, FI, NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

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**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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**Further documents are listed in the continuation of Box C.**  
**See patent family annex.**

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**Date of the actual completion of the international search**  
10 June 1993

**Date of mailing of the international search report**  
16-06-1993

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