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Europäisches Patentamt  
European Patent Office  
Office européen des brevets



11 Publication number:

**0 347 344 B1**

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## EUROPEAN PATENT SPECIFICATION

45 Date of publication of patent specification: **08.06.94** 51 Int. Cl.<sup>5</sup>: **B22C 9/04**, B22C 13/08

21 Application number: **89420208.4**

22 Date of filing: **12.06.89**

54 **Ceramic shell mold for investment casting and method of making the same.**

30 Priority: **13.06.88 US 205731**

43 Date of publication of application:  
**20.12.89 Bulletin 89/51**

45 Publication of the grant of the patent:  
**08.06.94 Bulletin 94/23**

84 Designated Contracting States:  
**DE FR GB**

56 References cited:  
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**DE-A- 3 015 639**  
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**Description**FIELD OF THE INVENTION

5 The invention relates to investment casting and, more particularly, to a ceramic shell mold for investment casting high melting point metals and alloys and a method for forming the ceramic shell mold according to the preambles of claims 10 and 1, respectively.

BACKGROUND OF THE INVENTION

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In the investment casting of high melting point metals and alloys, silica bonded ceramic shell molds conventionally have been used to contain and shape the molten material. Bulging and cracking of conventional silica bonded ceramic shell molds have been experienced in the investment casting of recently developed high melting point alloys at casting temperatures above 1480° C because of the low flexural strength and low creep resistance of such shell molds at the higher casting temperatures. When the ceramic shell mold bulges, the dimensions of the resultant casting are not accurate. Significant cracking can result in failure of the ceramic shell mold and runout of the molten material.

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To achieve better performance than conventional silica bonded ceramic shell molds provide at higher casting temperatures ceramic shell molds having an alumina, mullite, or other highly refractory oxide bond have been used. These bond materials normally are incorporated into the shell molds via slurries or suspensions of the ceramic material. Ceramic shell molds bonded with highly refractory oxides, however, suffer from one or more of the following disadvantages. The required ceramic slurries typically are difficult to control with respect to suspension stability, viscosity, and drainage. Further, the slurry coatings are difficult to dry and cure. These shell molds must be fired to a high temperature to achieve adequate sintering or chemical bonding. The shell molds also may be too strong during post-cast cooling, thereby inducing hot tears and/or recrystallization in the cast metal. In addition, such shell molds can be too strong and chemically inert at room temperature to be easily removed from the casting.

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Attempts also have been made to strengthen conventional silica bonded ceramic shell molds by reinforcing with a ceramic bracing network. Other efforts to overcome the inadequate high temperature properties of conventional silica bonded ceramic shell molds have focused on redesigning the part to be cast or changing the manner in which it is cast. These methods, however, are expensive, labor intensive, and, in most instances, impractical.

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The British Patent 1577836, which corresponds to DE-A-27 16 342, upon which the preambles of claims 1 and 10 are based, discloses a process for manufacturing a ceramic shell mold by dipping the meltable pattern in a slurry of a first ceramic material, made of silica and calcia, applying repeatedly a stucco of dry ceramic particles to the wet slurry coated surface and drying until the required mold thickness is obtained. This multilayer but homogeneous coating, forming a high viscosity glass-like phase during the firing step, provides a surface which is non-reactive with molten superalloys, allowing a better dimensional control and a better surface finish of the casting part, but the mechanical strength and the creep resistance are not sufficient for casting the newly developed high melting point superalloys.

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Accordingly, it is an object of the invention to provide a ceramic shell mold having improved mechanical properties at high temperatures.

Another objective of the invention is to provide a ceramic shell mold which facilitates improved control of casting dimensions and which can be easily removed from the casting.

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A further objective of the invention is to provide a method for making a ceramic shell mold having improved mechanical properties at high temperatures.

Additional objects and advantages will be set forth in part in the description which follows, and in part, will be obvious from the description or may be learned by practice of the invention.

50 SUMMARY OF THE INVENTION

To achieve the foregoing objects in accordance with the purpose of the invention, as embodied and broadly described herein, the ceramic shell mold of the present invention includes a facecoat layer comprised of a first ceramic material. A plurality of alternating layers overlay the facecoat layer. The alternating layers are comprised of a second ceramic material and a third ceramic material, the third ceramic material having thermophysical properties different than the second ceramic material. If desired, a cover layer overlaying the alternating layers may be provided. The resultant ceramic shell mold has a greater high temperature creep resistance than a shell mold formed solely from the second ceramic

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material or solely from the third ceramic material.

In the method of the present invention for forming the ceramic shell mold, a pattern having the shape of the desired casting is provided. A facecoat layer is formed by applying a first ceramic material on the pattern, preferably by dipping the pattern into a slurry comprised of the first ceramic material. A plurality of alternating layers overlaying the facecoat layer then are formed. The alternating layers are formed by alternately applying a second ceramic material and a third ceramic material on the coated pattern, the third ceramic material having thermophysical properties different than the second ceramic material. In a preferred embodiment, the alternating layers are formed by alternately dipping the coated pattern into slurries comprised of the second ceramic material and the third ceramic material, respectively. Each dipping step is followed by the step of applying a ceramic stucco on the ceramic slurry layer and drying. If desired, the method may include the step of forming a cover layer overlaying the alternating layers.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a transmitted light photomicrograph of the interface between an alumina-based layer and a zircon-based layer in a ceramic shell mold formed in accordance with the invention.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the present preferred embodiments of the invention.

In accordance with the invention, a pattern having the shape of the desired casting is provided. The pattern may be made of wax, plastic, frozen mercury, or other materials suitable for use in "lost wax" casting processes.

A facecoat layer then is formed on the pattern by applying a first ceramic material. The ceramic material is preferably an alumina-based or zircon-based material. The facecoat layer preferably is formed by dipping the pattern into a first slurry comprised of the first ceramic material. After allowing excess slurry to drain from the coated pattern, ceramic stucco is applied. The ceramic stucco may be coarse alumina (120 mesh or coarser) or other suitable refractory material. The facecoat layer is allowed to dry prior to the application of additional layers.

In accordance with the invention, a plurality of alternating layers overlaying the facecoat layer are formed by alternately applying a second ceramic material and a third ceramic material on the coated pattern. As used in connection with the description of the invention, a sequence of "alternating" layers is any sequence of layers including at least one layer of the second ceramic material and at least one layer of the third ceramic material. Thus, where A represents the second ceramic material and B represents the third ceramic material, sequences of layers such as ABABAB, AAABAA, AABBA, and BBBABB are all sequences of alternating layers.

The second and third ceramic materials are preferably applied by alternately dipping the coated pattern into a second ceramic slurry comprised of the second ceramic material and a third ceramic slurry comprised of the third ceramic material. Each dipping step is followed by the step of applying a ceramic stucco on the ceramic slurry layer and drying. While not preferred, it is possible to omit applying ceramic stucco on either the facecoat layer or any of the alternating layers.

In addition to dipping in a slurry, the alternating layers, as well as the facecoat layer, may be applied by spray coating or flow coating. When the layers are applied by spray coating or flow coating, the ceramic slurry is thinned, if necessary, with an appropriate solvent to provide for suitable handling.

In accordance with the invention, the third ceramic material has thermophysical properties different than the second ceramic material. A ceramic shell mold formed of alternating layers of ceramic materials having different thermophysical properties has better high temperature properties than a ceramic shell mold formed solely from either individual ceramic material. As used in connection with the description of the invention, "thermophysical properties" refer to the physical characteristics of a material at elevated temperatures. While not fully understood, it is believed that a mismatch in a physical characteristic such as strength or creep resistance between the alternating layers causes the shell mold to act as a composite material, with the layers of one material reinforcing the layers of the other material. Suitable materials having different thermophysical properties include, but are not limited to, alumina, mullite, zirconia, yttria, thoria, zircon, silica, an alumino-silicate containing less than 72 wt% alumina, and compounds, mixtures, or alloys thereof.

While not required, the ceramic material used to form the facecoat layer, previously referred to as the first ceramic material, may be substantially the same as either of the second or third ceramic materials used in forming the alternating layers. As used herein, ceramic materials that are "substantially the same" are ceramic materials that are identical or differ in that one ceramic material contains additional components

that do not materially affect the properties of the other ceramic material.

In a preferred embodiment, the alternating layers are formed by alternately dipping the coated pattern into an alumina-based slurry containing a silica binder and a zircon-based slurry containing a silica binder. The number of alternating layers required for adequate shell mold build-up depends on the nature of the casting operation in which the shell mold is to be used. Examples of shell mold constructions for a nine-layer shell mold, where the alternating layers are formed from an alumina-based material (represented by A) and a zircon-based material (represented by Z), include: ZZZAZAZAZ, ZAZAZAZAZ, AZAZAZAZA, ZZZAZAZAZ, ZZZAZAZAZ, ZAAZAAZAA, ZZZAZAZAZ, ZZZAZAZAZ, ZZZAZAZAZ, and ZZZAZAZAZ.

In a most preferred embodiment, seven alternating layers overlaying the facecoat layer are formed. The first, second, fourth, and sixth layers are formed by dipping the pattern into the zircon-based slurry. The third, fifth, and seventh layers are formed by dipping the pattern into the alumina-based slurry. As stated above, ceramic stucco is preferably applied after each dipping step.

If desired, a cover or seal layer may be formed overlaying the plurality of alternating layers. No stucco is applied to a cover layer. The cover layer may be formed of either the first, second, or third ceramic material, or a different ceramic material. A plurality of cover dips also may be applied.

Once the shell mold is built-up to the desired number of layers, it is thoroughly dried and the pattern is removed therefrom. Conventional techniques, such as melting, dissolution, and/or ignition may be used to remove the pattern from the shell mold. Following pattern removal, it is desirable to fire the shell mold at a temperature of approximately 980 °C for approximately one hour in an oxidizing, reducing, or inert atmosphere.

At this point, the fired shell mold is ready for use in the investment casting of metals and alloys, including high melting point metals and alloys. Prior to casting, however, the shell mold may be preheated to a temperature in the range of 90 °C to 1540 °C to insure that it is effectively free from moisture and to promote good filling of the molten material in all locations of the shell mold.

Equiaxed, directionally solidified, and single crystal castings of high melting point alloys, in particular nickel-based superalloys, may be produced in accordance with conventional investment casting techniques using the ceramic shell mold of the invention. After the molten material has cooled, the casting, which assumes the shape of the original wax pattern, is removed and finished using conventional methods.

The principles of the present invention described broadly above will now be described with reference to specific examples.

Example I

Mechanical property evaluations were conducted on ceramic shell molds of the invention and conventional shell molds. Shell plates (152,4 mm x 25,4mm) were fabricated on wax patterns in accordance with conventional dipping and stuccoing techniques. The dip sequences utilized were as follows:

Shell Mold No.	LAYER							Cover
	1	2	3	4	5	6	7	
1 (conventional)	Z	Z	Z	Z	Z	Z	Z	Z
2 (conventional)	A	A	A	A	A	A	A	A
3	Z	Z	Z	A	Z	A	Z	A
A = alumina-based slurry Z = zircon-based slurry								

Following build-up, the shell molds were dried, dewaxed in a steam autoclave, and fired at 1010 °C for 1 hour in an air atmosphere. The shell molds then were trimmed to the desired test specimen size via diamond saw cutting. Four-point modulus of rupture (MOR) and cantilever slump (also known as creep or sag) were measured at 1540 °C in an air atmosphere for each shell mold. MOR testing was conducted on "flat," 87,63mm x 19,05 mm specimens loaded with 25,4 mm upper span and 50,8 mm lower span. The crosshead speed was 5,08 mm/minute. Slump testing was conducted on "flat," 127 mm x 19,05 mm specimens, of which 38,1 mm of the specimen was held fixed and 88,9 mm of the specimen was unsupported (cantilevered) during the high temperature test exposure. The results of the MOR and slump testing at 1540 °C were as follows:

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Shell Mold No.	Average MOR (MPa) at 1540 ° C	Average Slump (mm) at 1540 ° C
1	1,24	10.6
2	7,6	12.4
3	2,55	6.0

As shown above, shell mold No. 3 having the alternating layer construction of the invention demonstrated higher strength than shell mold No. 1 (formed solely from zircon-based material), advantageously lower strength than shell mold No. 2 (formed solely from alumina-based material), and less slump than either shell mold No. 1 or No. 2. Such surprising slump performance results would not have been predicted via a rule-of-mixtures model. As can be seen in Fig. 1, which is a photomicrograph of the interface between an alumina-based layer and a zircon-based layer, there is no apparent reaction or new phase formation to account for the improvement in mechanical properties for the shell mold of the invention. This observation is further supported by X-ray diffraction analyses which revealed no new phase formation. In Fig. 1, the bottom half of the photomicrograph is the zircon-based layer. The top half is the alumina-based layer. The large white grain in the upper left hand corner is an alumina stucco grain.

Example II

The following shell mold systems were tested in the manner described above in Example I:

Shell Mold No.	LAYER								Cover	Cover
	1	2	3	4	5	6	7	8		
4	Z	Z	A	Z	Z	Z	Z	Z	Z	-
5	Z	Z	A	Z	Z	Z	Z	Z	A	A
6	Z	Z	Z	A	Z	A	Z	A	Z	-

A = alumina-based slurry  
Z = zircon-based slurry

As can be seen below, the test results demonstrate the improved high temperature mechanical properties of shell molds encompassed by the invention.

Shell Mold No.	Average MOR (MPa) at 1540 ° C	Average Slump (mm) at 1540 ° C
4	3,3	3.5
5	3,7	1.9
6	5,4	2.8

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Example III

The following shell systems also were tested in the manner described above in Example I:

Shell Mold No.	LAYER								Cover
	1	2	3	4	5	6	7	8	
7 (conventional)	Z	Z	Z	Z	Z	Z	Z	Z	Z
8	A	A	Z	Z	Z	Z	Z	Z	Z
9	Z	A	Z	A	Z	A	Z	A	Z
10	Z	Z	A	A	Z	A	A	Z	A
11	A	A	Z	A	A	Z	A	A	Z

A = alumina-based slurry  
Z = zircon-based slurry

The tests results shown below further demonstrate the improved high temperature mechanical properties of shell molds of the present invention (shell mold Nos. 8, 9, 10, and 11) in comparison with conventional shell molds (shell mod No. 7).

Shell Mold No.	Average MOR (MPa) at 1540 ° C	Average Slump (mm) at 1540 ° C
7	1,24	9.4
8	1,86	2.8
9	2,62	3.4
10	6,9	5.2
11	11,0	7.3

The present invention has been disclosed in terms of preferred embodiments. The invention is not limited thereto and is defined by the appended claims and their equivalents.

**Claims**

- A method for forming a ceramic shell mold for investment casting high melting point metals and alloys by :
  - providing a pattern having the shape of the desired casting
  - forming on the pattern a facecoat layer by application of a first ceramic material
  - overlaying the facecoat layer by application of a second ceramic material
 characterized by forming a plurality of alternating layers by alternately applying the second ceramic material and a third ceramic material having thermophysical properties different from the second ceramic material
- The method of claim 1, wherein the second and the third ceramic materials are selected from the group consisting of alumina, mullite, zirconia, yttria, thoria, zircon, silica, an alumino-silicate containing less than 72 wt% alumina, and compounds, mixtures, or alloys thereof.
- The method of claim 1, wherein the first and second ceramic materials are substantially the same.
- The method of claim 1, wherein the first and third ceramic materials are substantially the same.
- The method of claim 1, wherein the alternating layers are overlaid by a cover layer.
- The method of claim 1, wherein seven layers are formed on the facecoat layer, the first, second, fourth, and sixth layers being formed by applying a zircon-based material, and the third, fifth and seventh layers being formed by applying an alumina-based material.

7. The method of claim 1, wherein the first, second and third ceramic materials are applied by dipping the coated pattern in slurries comprised of these materials.
8. The method of claim 1, wherein at least one step of alternately applying the second and the third ceramic material is followed by applying a ceramic stucco on the alternating layers and drying.
9. The method of claim 1, wherein the alternating layers are respectively comprised of alumina-based and zircon-based slurries.
10. A ceramic shell mold for investment casting high melting point metals and alloys comprising a facecoat layer of a first ceramic material overlaid by a layer of a second ceramic material, characterized by a plurality of alternating layers overlaying the facecoat layer comprised of the second ceramic material and a third ceramic material having thermophysical properties different from the second ceramic material.
11. The ceramic shell mold of claim 10, wherein the second and third ceramic materials are selected from the group consisting of alumina, mullite, zirconia, yttria, thoria, zircon, silica, an alumino-silicate containing less than 72 wt % alumina, and compounds, mixtures or alloys thereof.
12. The ceramic shell mold of claim 10, wherein the first and second ceramic materials are substantially the same.
13. The ceramic shell mold of claim 10, wherein the first and third ceramic materials are substantially the same.
14. The ceramic shell mold of claim 10, wherein the alternating layers are comprised respectively of alumina-based and zircon-based slurries.
15. The ceramic shell mold of claim 10, wherein the alternating layers overlaying the facecoat layer comprise at least seven layers, the first, second, fourth and sixth layers being of zircon-based material and the third, fifth and seventh layers being of alumina-based material.

#### Patentansprüche

1. Verfahren zur Bildung einer Keramikschaalenform zum Feinguß von Hochschmelzpunktmetallen und -legierungen durch:
- Vorsehen eines Modells mit der Form des gewünschten Gußstücks,
  - Bilden einer Flächenüberzugsschicht auf dem Modell durch Aufbringen eines ersten Keramikmaterials,
  - Überziehen der Flächenüberzugsschicht durch Aufbringen eines zweiten Keramikmaterials,
- gekennzeichnet** durch
- Bilden einer Mehrzahl abwechselnder Schichten durch abwechselndes Aufbringen des zweiten Keramikmaterials und eines dritten Keramikmaterials mit vom zweiten Keramikmaterial verschiedenen thermophysikalischen Eigenschaften.
2. Verfahren nach Anspruch 1, bei dem das zweite und das dritte keramische Material aus der aus Aluminiumoxid, Mullit, Zirkonoxid, Yttriumoxid, Thoriumoxid, Zirkon, Siliziumdioxid, einem weniger als 72 Gew.% Aluminiumoxid enthaltenden Aluminiumsilikat und deren Verbindungen, Mischungen oder Legierungen bestehenden Gruppe gewählt werden.
3. Verfahren nach Anspruch 1, bei dem das erste und das zweite Keramikmaterial im wesentlichen die gleichen sind.
4. Verfahren nach Anspruch 1, bei dem das erste und das dritte Keramikmaterial im wesentlichen die gleichen sind.
5. Verfahren nach Anspruch 1, bei dem die abwechselnden Schichten mit einer Abdeckschicht überzogen werden.

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6. Verfahren nach Anspruch 1, bei dem sieben Schichten auf der Flächenüberzugsschicht gebildet werden, wobei die erste, zweite, vierte und sechste Schicht durch Aufbringen einer Zirkonbasisschicht gebildet werden und die dritte, fünfte und siebente Schicht durch Aufbringen eines Aluminiumoxidbasis-
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7. Verfahren nach Anspruch 1, bei dem das erste, zweite und dritte Keramikmaterial durch Eintauchen des überzogenen Modells in aus diesen Materialien gebildete Aufschlämmungen aufgebracht werden.
8. Verfahren nach Anspruch 1, bei dem auf wenigstens einen Schritt des abwechselnden Aufbringens des zweiten und des dritten Keramikmaterials ein Aufbringen eines Keramikstücks auf die abwechselnden Schichten und ein Trocknen folgen.
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9. Verfahren nach Anspruch 1, bei dem die abwechselnden Schichten aus Aluminiumoxidbasis- bzw. Zirkonbasis-Aufschlämmungen bestehen.
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10. Keramikschaalenform zum Feinguß von Hochschmelzpunktmetallen und -legierungen, die eine Flächenüberzugsschicht aus einem ersten Keramikmaterial aufweist, die mit einer Schicht aus einem zweiten Keramikmaterial überzogen ist, gekennzeichnet durch eine Mehrzahl über der Flächenüberzugsschicht liegender abwechselnder Schichten, die aus dem zweiten Keramikmaterial und einem dritten Keramikmaterial mit vom zweiten Keramikmaterial verschiedenen thermophysikalischen Eigenschaften bestehen.
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11. Keramikschaalenform nach Anspruch 10, bei der das zweite und das dritte Keramikmaterial aus der aus Aluminiumoxid, Mullit, Zirkonoxid, Yttriumoxid, Thoriumoxid, Zirkon, Siliziumdioxid, einem weniger als 72 Gew.-% Aluminiumoxid enthaltenden Aluminiumsilikat und deren Verbindungen, Mischungen oder Legierungen bestehenden Gruppe gewählt werden.
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12. Keramikschaalenform nach Anspruch 10, bei der das erste und das zweite Keramikmaterial im wesentlichen die gleichen sind.
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13. Keramikschaalenform nach Anspruch 10, bei der das erste und das dritte Keramikmaterial im wesentlichen die gleichen sind.
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14. Keramikschaalenform nach Anspruch 10, bei der die abwechselnden Schichten aus Aluminiumoxidbasis- bzw. Zirkonbasisaufschlämmungen bestehen.
15. Keramikschaalenform nach Anspruch 10, bei der die über der Flächenüberzugsschicht liegenden abwechselnden Schichten wenigstens sieben Schichten aufweisen, wobei die erste, zweite, vierte und sechste Schicht aus Zirkonbasismaterial sind und die dritte, fünfte und siebente Schicht aus Aluminiumoxidbasismaterial sind.

### Revendications

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1. Procédé permettant de confectionner un moule-carapace en céramique destiné au moulage de précision à modèle perdu des métaux ou alliages à point de fusion élevé par :
- fourniture d'un modèle qui possède la forme de la pièce moulée souhaitée
  - formation, sur le modèle, d'une couche de contact par application d'un premier matériau céramique
  - recouvrement de la couche de contact par application d'un deuxième matériau céramique,
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- caractérisé en ce que l'on forme une pluralité de couches alternées en appliquant tour à tour le deuxième matériau céramique et un troisième matériau céramique qui possède des caractéristiques thermophysiques différentes de celles du deuxième matériau céramique.
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2. Procédé de la revendication 1, dans lequel les deuxième et troisième matériaux céramiques sont choisis dans le groupe constitué par l'alumine, la mullite, la zircone, l'oxyde d'yttrium, la thorine, le zircon, la silice, un alumino-silicate contenant moins de 72 % en poids d'alumine et les composés, mélanges ou alliages de ces corps.

3. Procédé de la revendication 1, dans lequel les premier et deuxième matériaux céramiques sont sensiblement les mêmes.
- 5 4. Procédé de la revendication 1, dans lequel les premier et troisième matériaux céramiques sont sensiblement les mêmes.
5. Procédé de la revendication 1, dans lequel les couches alternées sont recouvertes par une couche de couverture.
- 10 6. Procédé de la revendication 1, dans lequel on forme sept couches sur la couche de contact, les première, deuxième, quatrième et sixième couches étant formées par application d'un matériau à base de zircon, tandis que les troisième, cinquième et septième couches sont formées par application d'un matériau à base d'alumine.
- 15 7. Procédé de la revendication 1, dans lequel on applique les premier, deuxième et troisième matériaux céramiques en immergeant le modèle revêtu dans des barbotines constituées de ces matériaux.
8. Procédé de la revendication 1, dans lequel au moins l'une des étapes consistant à appliquer tour à tour le deuxième et le troisième matériaux céramiques est suivie par l'application d'un stuc céramique sur les couches alternées et par un séchage.
- 20 9. Procédé de la revendication 1, dans lequel les couches alternées sont constituées respectivement d'une barbotine à base d'alumine et d'une barbotine à base de zircon.
- 25 10. Moule-carapace en céramique destiné au moulage de précision à modèle perdu des métaux ou alliages à point de fusion élevé, comportant une couche de contact constituée d'un premier matériau céramique, recouverte par une couche d'un deuxième matériau céramique, caractérisé en ce que la couche de contact est recouverte par une pluralité de couches alternées constituées du deuxième matériau céramique et d'un troisième matériau céramique qui possède des caractéristiques thermophysiques différentes de celles du deuxième matériau céramique.
- 30 11. Moule-carapace en céramique de la revendication 10, dans lequel le deuxième et le troisième matériaux céramiques sont choisis dans le groupe constitué par l'alumine, la mullite, la zircone, l'oxyde d'yttrium, la thoria, le zircon, la silice, un alumino-silicate contenant moins de 72 % en poids d'alumine et les composés, mélanges ou alliages de ces corps.
- 35 12. Moule-carapace en céramique de la revendication 10, dans lequel les premier et deuxième matériaux céramiques sont sensiblement les mêmes.
- 40 13. Moule-carapace en céramique de la revendication 10, dans lequel les premier et troisième matériaux céramiques sont sensiblement les mêmes.
14. Moule-carapace en céramique de la revendication 10, dans lequel les couches alternées sont constituées respectivement d'une barbotine à base d'alumine et d'une barbotine à base de zircon.
- 45 15. Moule-carapace en céramique de la revendication 10, dans lequel les couches alternées recouvrant la couche de contact comportent au moins sept couches, les première, deuxième, quatrième et sixième couches étant constituées de matériau à base de zircon, tandis que les troisième, cinquième et septième couches sont constituées de matériau à base d'alumine.
- 50

**FIG. 1**

