United States Patent

Ingalls et al.

[15] **3,669,177**

[45] **June 13, 1972**

[54] **SHELL MANUFACTURING METHOD FOR PRECISION CASTING**

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[21] Appl. No.: **855,941**

[52] **U.S. Cl.** **164/26,** 164/34, 164/27, 164/129

[51] **Int. Cl.** **B22c 9/00**

[58] **Field of Search** 164/24, 25, 26, 129, 35, 36, 164/77, 129, 137, 23, 30, 31, 27, 29, 28

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[57] **ABSTRACT**

The preparation of a composite shell mold for precision casting wherein portions of the shell mold of large dimension and complicated shapes are formed by the lost wax process while other portions are formed by conventional molding or permanent molding techniques for joinder into a composite mold.

16 Claims, 11 Drawing Figures

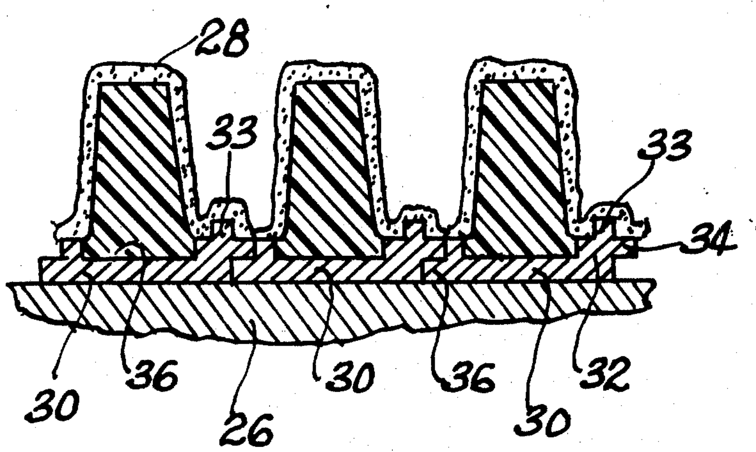

FIG. 1

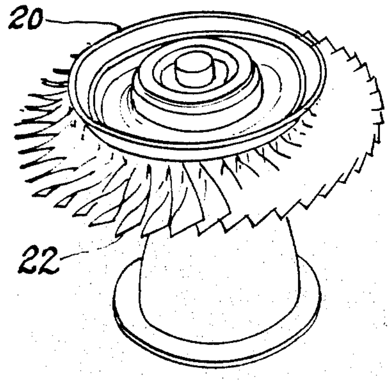

FIG. 2

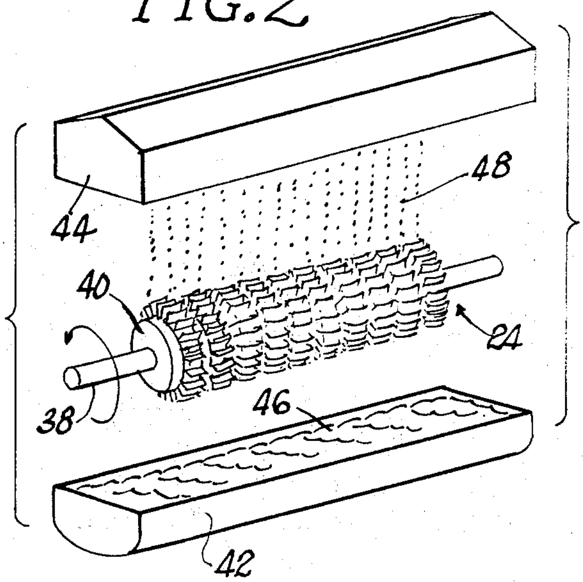

FIG. 3

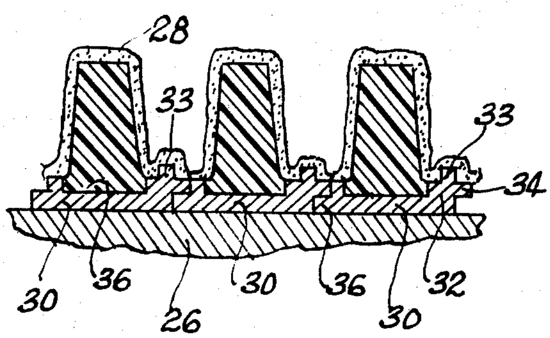

FIG. 4

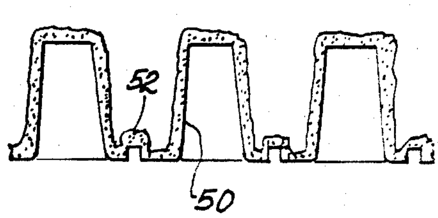

FIG. 5

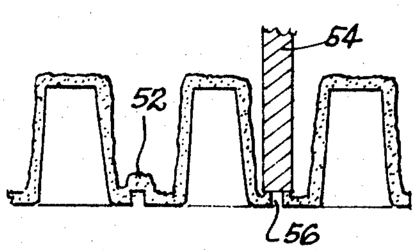

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FIG. 6

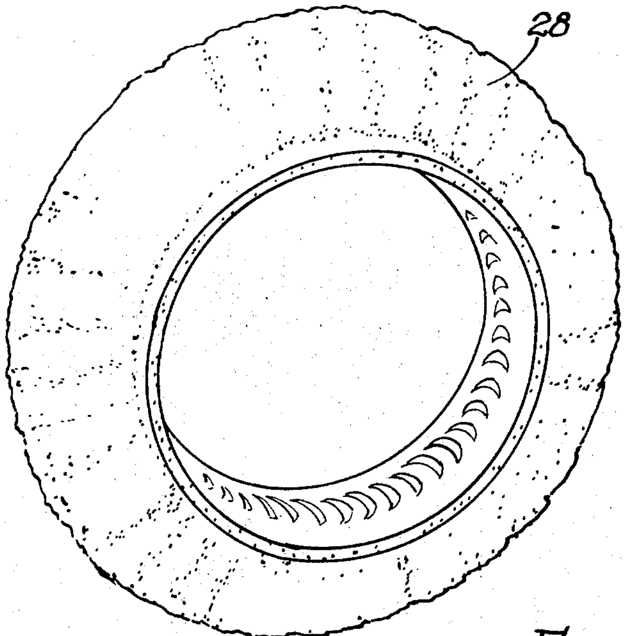
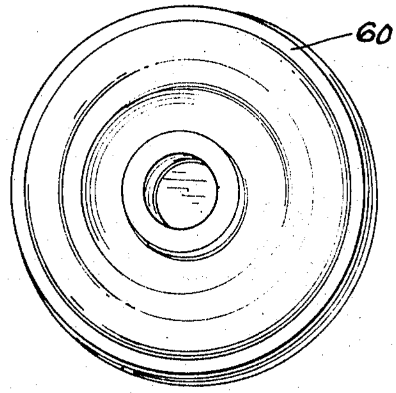


FIG. 7



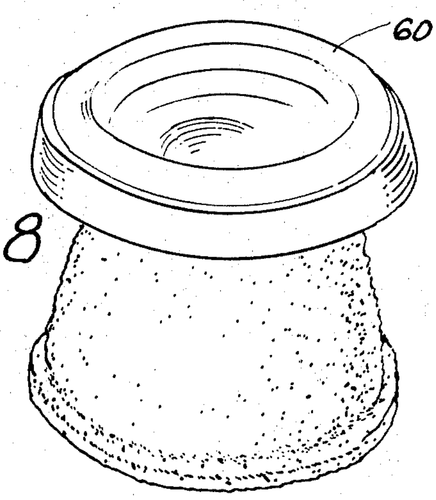


FIG. 8

FIG. 9

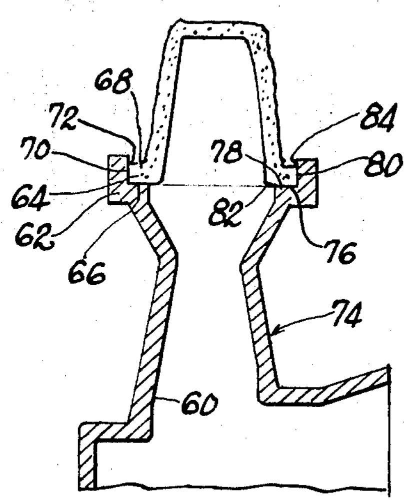


FIG. 10

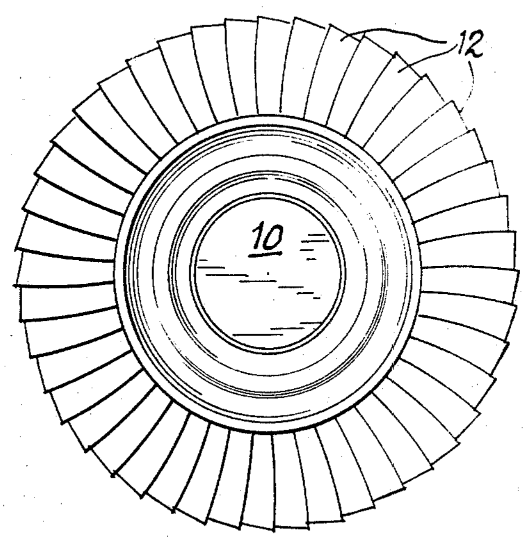
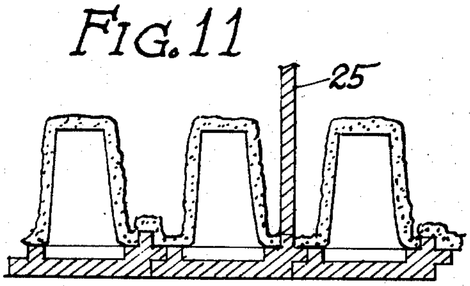


FIG. 11



SHELL MANUFACTURING METHOD FOR PRECISION CASTING

This invention relates to the process for precision casting of metal parts of large dimension and of complex shapes and it relates more particularly to the casting of parts of large dimension and complex shapes as an integral unit.

To the present, as described in the issued patent of Operhall et al., U.S. Pat. No. 2,961,751, integral castings of complex shapes have been precision cast of super alloys by the assembly of a plurality of heat disposable patterns, conforming to the parts to be molded, into a cluster having the necessary sprues and runners, similarly formed of heat disposable material. The cluster is then processed through a series of alternating dip coats and stucco coats of ceramic materials to build up a ceramic shell about the exposed surfaces of the cluster. After sufficient drying or setting of the applied dip and stucco coats, the cluster with the shell of ceramic material formed thereon is exposed to high temperature to melt and to burn out the heat disposable material, leaving a ceramic shell containing spaces formerly occupied by the heat disposable patterns and inter-connected by channels formerly occupied by the gates and runners. The ceramic shell is further heated to cure and/or preheated prior to pouring the molten metal therein. The molten metal flows through the gates and runners to fill the cavities formerly occupied by the heat disposable patterns. After cooling to solidify the metal, the ceramic shell is broken away to expose the integral casting from which the metal parts are separated and cleaned. The described precision casting process embodies the principles of the "lost wax process" but with considerable improvement for precision casting of complicated shapes of super alloys and metals which otherwise are difficult to process.

The described precision casting process, as it is practiced today, requires considerable labor for use in the fabrication of a pattern and the assembly of patterns into a cluster having a suitable design and arrangement for use in a ceramic shell from which molded parts can be secured in high yield. Further, the size or dimension of the parts that can be joined into a single pattern or cluster for producing an integral casting is limited, such that it is difficult to cast parts such as an entire wheel having a plurality of turbine blades formed integrally with the hub of the wheel and extending outwardly radially therefrom in uniformly spaced apart relation and with sufficient assurance that the blades will be completely filled for an acceptable composite casting capable of meeting rigid specifications. The turbine wheel described is merely illustrative of the type of structure having a size and shape which is difficult to cast by current precision casting techniques.

It is an object of this invention to provide a process for the preparation of composite molds from which integral castings of large dimension and/or shapes can be produced in high yields by the precision casting process; in which the composite mold is formed of separate parts capable of being assembled together to provide a composite mold in which the molten metal can be poured to produce an integral metal casting; in which separate parts of the mold are capable of fabrication by more efficient and effective techniques for more accurate and more economical production of the parts with corresponding increase in yield of metal castings produced therefrom; and in which such parts can be assembled to produce shells from which castings of large dimension or complicated shapes can be produced.

These and other objects and advantages of this invention will hereinafter appear and, for purposes of illustration, but not of limitation, an embodiment of the invention is shown in the accompanying drawings, in which

FIG. 1 is a perspective view of a molded pattern of the multi-bladed air foil for use in the casting of a multi-bladed turbine wheel;

FIG. 2 is a perspective view of the assembly of a number of the air foil patterns of FIG. 1 in a roll assembly;

FIG. 3 is a sectional elevational view of a portion of the roll assembly of FIG. 2 showing the ceramic shell formed about the patterns;

FIG. 4 is a sectional elevational view similar to that of FIG. 3 showing the air foil shell after removal of the pattern of heat disposable metal;

FIG. 5 is a sectional elevational view similar to that of FIG. 4 showing the removal of the portion of shell interconnecting the axially aligned air foil shells for separation into air foil sections;

FIG. 6 is a perspective view of the separated shell for casting the wheels;

FIG. 7 is a perspective view of a disc plate molded of ceramic material;

FIG. 8 is a perspective view of the pouring cup molded of ceramic material;

FIG. 9 is a sectional view through a portion of the assembly showing the disc plate and pouring cup joined to the air foil shell to form the composite shell mold;

FIG. 10 is a perspective view of the integral turbine wheel cast in the shell mold of FIG. 9; and

FIG. 11 is a view similar to that of FIG. 3 showing the use of separator discs between pattern parts.

The invention will be described with reference to the preparation of a composite mold for casting an integral turbine wheel having a central hub portion **10** with a plurality of air foil blades **12** extending radially outwardly from the periphery of the hub portion. It will be understood that the concepts described for the fabrication of the composite mold for casting the turbine wheel are applicable also to the preparation of composite molds of multiple parts for the casting of other products of large dimension and/or complicated shapes.

Furthermore, since the invention is addressed primarily to the elements of the shell mold, their manufacture and assembly to produce the completed composite mold into which the metal may be cast, detailed description will not be given of the composition from which the patterns are formed or of the dip coat and stucco composition used to form the ceramic shell about the various segments of the mold. Compositions suitable for use in the fabrication of the pattern parts and the shell are disclosed in numerous patents on precision casting. For this purpose, reference may be made to the aforementioned Operhall et al. patent or to U.S. Pat. Nos. 2,441,695, 3,196,506 and 3,132,388.

Suffice it to say that the pattern parts are formed of a disposable material to enable removal from the mold after the ceramic shell has been formed thereon. The pattern parts are preferably formed of a heat disposable material, such as wax and more preferably a plastic material which can be molded by conventional molding techniques for accurate reproduction of the part to be molded, such as polystyrene, polymethyl methacryate.

Referring now to the drawings, FIG. 1 illustrates the pattern conforming to the air foil having a central rim portion **20**, in the form of a cylindrical section, with a plurality of blades or vanes **22** extending outwardly radially from the outer peripheral surface of the rim in circumferentially spaced apart relation. The rim section and the separate blades can be separately formed and assembled by cementing the individual blades to the rim. It is preferred, however, that the entire assembly be molded as an integral unit of a suitable thermoplastic material, such as polystyrene, polyethylene, polyvinyl acetate, vinyl chloride - vinyl acetate copolymer and the like, whereby the assembly can be produced at much lower cost with assured accuracy in the location and arrangement of the blades.

As illustrated in FIGS. 2 and 3, a number of such integrally molded air foils sections **24** are mounted in side by side, axially aligned relation on a supporting drum **26** for rotational movement as a unit to form a ceramic shell **28** about the assembled, laterally spaced apart air foil patterns. For this purpose, each pattern portion **24** is mounted on a supporting sleeve **30** dimensioned to be received in fitting relationship within the rim **10**, with each sleeve **30** being formed at its ends beyond the rim with an axial extension **32** having an annular flange **33** of rectangular cross section with means for securing one section to another, such as forming the flange **33** with an axial tongue **34** and groove **36** arranged for inter-fitting with tongues and grooves in the ends of adjacent sleeve members for the assembly of two or more sleeve sections into an interconnected unit. The sleeve sections are mounted on the supporting drum **26** having an axle **38**. Clamping discs **40** are axially slidable on the axle into engagement with the outermost sleeve section to clamp the sleeve section in their assembled relationship on the drum.

The axles are mounted for turning movement, as indicated by the arrow in FIG. **2**, to effect rotational movement of the patterns mounted on the drum. Also, the axle **38** is supported for movement in a horizontal direction between a dip tank **42** and a stucco hood **44** offset one from the other and for movement in the vertical direction to enable the pattern assembly to be lowered for immersion of the patterns to a level above the rim portion into a bath **46** of the dip coat composition to coat the entire exposed surfaces of the pattern with the dip coat composition as the assembly is slowly turned.

When the pattern has been rotated during immersion for at least one and preferably a number of complete revolutions to insure uniform wetting of the pattern cluster, the entire assembly is raised from the dip coat composition and displaced to a position below the hood **44** while continuously revolving the assembly to maintain a uniform coating of the dip coat composition on the pattern surfaces. Stucco is sprayed onto the pattern wet with the dip coat composition while rotational movement is continued uniformly to stucco the pattern with ceramic material, such as particles of alundum, zircon and the like. It will be understood that, instead of moving the drum with the assembled patterns between the dip coat station and the stucco station, the drum with the assembled patterns can be mounted for rotational movement in a single location while the tank **42** containing the dip coat composition is brought into position beneath the assembly and raised for partial immersion of the patterns into the dip coat composition and the stucco hood is moved, in turn, into position over the assembly wet with the dip coat composition for applying the stucco **48** to the wet surfaces of the pattern.

The described operations are repeated for a number of cycles, preferably with interim drying or setting until a ceramic shell **28** of the desired thickness has been built up about the assembled patterns, as illustrated in FIG. **3**.

Thereafter, the drawn **26** and the sleeves **30** are removed and the composite formed of the patterns and ceramic shell is introduced into a chamber heated to a temperature above the melting point temperature of the material making up the pattern, and preferably to a temperature within the range of 1,500° to 2,100° F. At such temperature, heat transfers rapidly through the ceramic shell to reduce the pattern material to flowable or combustion temperature for flash removal of the pattern material. This leaves the ceramic shell with the hollow rim and connecting bladed portions corresponding in shape and dimension to the air foil wheel. Exposure to elevated temperature for a few minutes is sufficient completely to remove and burn out the pattern material and to cure the ceramic material making up the formed shell **50**.

The formed shell is processed to separate the air foil segments one from the other. For this purpose, the ceramic material in the raised portions **52** intermediate the segments is removed, as by means of a wire brush **54** or grinding wheel, as the assembly is rotated until the annular rim section **56** is reached cleanly to separate the segments one from the other without interference with the surfaces defining the mold section and to provide a surface **56** of predetermined contour and shape for receiving other parts in fitting relationship to form the completed shell for molding, as will hereinafter be described.

A disc plate **60**, dimensioned to span one side of the opened end of the air foil mold, is separately formed of ceramic material. In the preferred practice of this invention, the disc plate **60** is formed by compression molding, or by slip casting, or by injection molding directly of ceramic material to the shape and dimension for receipt in fitting relationship on one end of the shell mold **50** of the air foil section. If the disc plate **60** is of a contour that militates against the use of conventional molding techniques of the type described, the disc plate can be formed as a shell about a pattern of heat disposable material by the alternating cycles of dip coating, stuccoing and drying to form a shell about the pattern followed by removal of the pattern in the manner described to provide the disc plate of ceramic material.

It is preferred to produce the disc plate by compression or injection molding or by slip casting, since such techniques provide a low cost mold part which can be molded directly to the desired shape and to provide a mold surface having greater accuracy and smoothness.

Instead of providing the disc plate in the form of a cast or molded ceramic material, the disc plate or its equivalent can be provided in the form of a permanent member capable of repeated use as an element in a composite mold. For this purpose, the disc plate can be formed of graphite or of metal preferably cored for the passage of a coolant liquid, such as water, therethrough. Such construction with a cooled disc plate finds further utility for grain size and orientation control as described in U.S. Pat. No. 3,248,764.

The disc plate **60** is molded with outer end portions **62** having an annular groove **64** in its inner-face with an axial portion **66** dimensioned to be received in telescoping relation within the annular edge portion **68** of the air foil mold and a radial portion **70** which abuts against the radial surface **72** in the edge of the air foil mold formed by the annular flange **33** thereby to permit an interfitting relationship between the air foil shell **50** and the disc plate **60**. The mold sections are joined in their assembled relation by a suitable ceramic adhesive, such as sodium silicate, metal phosphate and the like with or without ceramic filler, to effect a bonded relationship between the mold segments. Instead, use can be made of a ceramic clip to hold the parts together.

The pouring spout **74** is similarly molded of ceramic material or by forming a ceramic shell about a pattern of disposable material. The pouring spout **74** is similarly adapted to be joined onto the other end of the air foil shell opposite the disc plate **60**. For this purpose the molded spout is formed with an annular groove **76** in its inner-face outwardly of the mold surface having a flat axial portion **78** and a flat radial portion **80** adapted to interfit with the inner portion **82** of the rim and the outer edge **84** of the air foil section to effect an assembled relationship therebetween.

The assembled mold parts are heated to cure the ceramic material and adhesive joints to form a composite, cured ceramic shell mold into which the molten metal can be poured.

In pouring, the ceramic shell is preheated to elevated temperature, approximating the temperature of the molten metal poured into the mold. The molten metal is poured into the mold while resting on the disc plate with the molten metal being introduced through the pouring spout in an amount to fill the mold cavity at least to the base of the pouring spout. The metal may be poured into a stationary shell or the shell may be rotated about its axis during the pouring of the metal centrifugally to displace the molten metal into the outermost recesses of the mold cavity thereby to insure complete filling of the bladed air foil sections prior to the inner body or hub portion of the mold. Thus a complete integral casting is secured of the bladed turbine wheel in a single molding operation.

By way of modification, the pattern sections **24** can be mounted on the supporting drum **26** in side by side relationship with a separator member **25** between pattern sections, preferably in the form of a thin, flexible disc member of rigid or thin paper or plastic material. The disc member is dimensioned to extend beyond the adjacent portions of the pattern sections by a substantial distance so as to enable the disc member to be broken away after the ceramic materials have been applied to build up the shell mold of the desired wall thickness. Thus the separator member **25** will maintain the shell parts in easily separated relation on their cylindrical support.

In the event that use is made of such disc shaped separating members between pattern parts, the interfitting tongue and groove arrangement previously described can be replaced by flat walls which are adapted to be joined to the walls of other shell parts making up the composite shell mold with the application of adhesive to the surfaces to be joined.

By way of still further modification, especially in connection with the use of such disc shaped separators or flanged separators of the type previously described, it will be understood that separation can be effected between the aligned pattern parts and the composite shell mold formed thereabout before removal of the pattern material. Thus it is the separated pattern with the ceramic shell that is subjected to heat treatment to effect pattern removal and cure of the ceramic shell material. This latter procedure of subdividing the composite shell prior to pattern removal is often preferred where the drum support might interfere with the ease or efficiency of heat treatment or with the removal of pattern material from within the ceramic shell. The subdivision is also preferred from the standpoint of contamination since subdivision of the ceramic shell subsequent to removal of the pattern can permit ceramic material to enter into the mold cavity during grinding to subdivide the composite shell.

Similarly, pattern removal can be effected by heat treatment after all of the shell parts have been assembled to form the composite shell mold whereby pattern removal for all of the parts can be effected in the one and same heat treatment to produce a composite and cured shell structure.

The described mono-rolled cluster of patterns can be carried out as a continuous operation. For this purpose, the drum roll with the pattern sections mounted thereon can be supported on a conveyor which is operatively engaged during movement to effect rotational movement of the drum as it is carried by the conveyor for immersion into the dip coat composition and as it rises from the dip coat composition, while it travels through a length for drainage and then the stuccoing hood wherein the stucco is sprayed onto the surfaces wet with the dip coat composition and from the stuccoing section to a driving section to complete a cycle of separation which can be repeated continuously and a number of times until the desired shell thickness has been built up on the disposable pattern.

It will be apparent from the foregoing that the concepts described are adapted to enable the preparation of composite molds for metal castings which are capable of use in the production of castings of large dimension or of complicated shape and particularly precision cast assemblies of air foil designs and wherein such molds can be produced in an efficient and economical manner for substantially mass production with a high yield of acceptable products.

While the invention has been described with reference to the preparation of molds of ceramic materials for the precision casting of super-alloys and high alloy steels, it will be understood that the concepts described for mold preparation may be adapted for the production of molds of graphite materials wherein the slip compositions are formulated of graphite flour and colloidal graphite while the stucco is selected of suitable particles of graphite to produce molds at least the inner portions of which are of graphitic composition.

It will be understood that changes may be made in the details of arrangement, construction and operation without departing from the spirit of the invention, especially as defined in the following claims.

We claim:

1. In a process for the precision casting of metal parts of large dimension or complicated shape in molds, the steps of preparation of the mold comprising separately preparing sections of the mold with edge portions that interfit one with another to form a composite mold which defines the mold cavity, at least one section of which comprises a circular section with edge portions for interfitting with other sections of the composite mold, which includes the steps of forming pattern elements of heat disposable material into a circular pattern assembly, rotating said circular pattern assembly while submerging at least a portion of the pattern in a fluid slip composition until all portions of the pattern assembly have been submerged uniformly to wet the pattern assembly over its entire surface, exposing the pattern wet with the slip coat composition to stucco for applying a stucco coat onto the surface wet with the slip composition, repeating the alternating steps of slip coating and stuccoing until a shell of the desired thickness has been formed about the heat disposable pattern, exposing the composite to a temperature sufficient to effect removal of heat disposable pattern material to leave the mold containing a cavity corresponding to the pattern assembly, molding the other sections of the mold of ceramic material with interfitting edge portions for joinder in an interfitting relation of the formed mold sections into a composite mold, joining the separate sections of the mold along their interfitting edge portions and then heating the assembly to cure the composite mold in which the circular pattern comprises an air foil section having a plurality of blades or vanes extending radially outwardly from a central hub section in circumferentially spaced apart relation.

2. A process as claimed in claim **1** in which the slip and stucco compositions comprise ceramic materials.

3. In a process for the precision casting of metal parts of large dimension or complicated shape in molds, the steps of preparation of the mold comprising separately preparing sections of the mold with edge portions that interfit one with another to form a composite mold which defines the mold cavity, at least one section of which comprises a circular section with edge portions for interfitting with other sections of the composite mold, which includes the steps of forming pattern elements of heat disposable material in a circular pattern assembly in which the elements extend outwardly radially from a central hub section in circumferentially spaced apart relation, mounting a plurality of said circular pattern assemblies in side-by-side axially aligned relationship on a cylindrical support for rotational movement together with the support, rotating said circular pattern assembly while submerging at least a portion of the pattern in a fluid slip composition until all portions of the pattern assembly have been submerged uniformly to wet the pattern assembly over its entire surface, exposing the pattern wet with slip coat composition to stucco for applying a stucco coating onto the surface wet with the slip composition, repeating the alternating steps of slip coating and stuccoing until a shell of the desired thickness has been formed about the heat disposable pattern, removing the patterns and composite shell formed thereon from the cylindrical support, exposing the composite to a temperature sufficient to effect removal of the heat disposable pattern material to leave the mold containing cavities corresponding to the pattern assembly, subdividing the composite shell mold into separate sections, molding other sections of the mold of ceramic material with interfitting edge portions for joinder in an interfitting relationship with the formed mold sections into a composite mold, joining the separate sections of the mold along their interfitting edges, and then heating the assembly to cure the composite mold.

4. A process as claimed in claim **3** in which the patterns are air foil patterns and which includes a step of separating the air foil patterns on the cylindrical support by a thin flexible disc shaped member dimensioned to extend beyond the adjacent end portions of the pattern.

5. A process as claimed in claim **3** in which the alternating layers of dip coat and stucco are applied by displacing the cylindrical support with the patterns mounted thereon to a position over a bath of the dip coat composition, lowering the assembly for a distance to immerse the patterns by an amount to wet the entire pattern assembly during rotation of the cylindrical support, raising the assembly from the bath after at least one rotation in the bath, displacing the assembly to a position offset from the bath and sprinkling the assembly with stucco while continuing to rotate the cylindrical support.

6. A process as claimed in claim 3 in which the alternating layers of dip coat and stucco are applied by positioning a bath of dip coat composition into position beneath the rotating support, raising the bath into position to immerse a portion of the pattern assembly sufficiently completely to wet the surfaces during rotation of the cylindrical support, lowering the bath after at least one revolution of the pattern assembly while immersed in the bath, displacing the bath from beneath the assembly and then sprinkling the assembly with stucco while continuing to rotate the cylindrical support.

7. A process as claimed in claim 3 in which the patterns of the sections are separated one from the other on the cylindrical support by an annular rim which defines an annular void between the shell sections in the composite mold and in which the shell sections are separated one from the other by removal of the portions of the shell radially of the rim whereby the cavity formed by the rim portion defines dimensionally controlled end sections for interfitting the shell with others of the shell parts to form the completed mold.

8. A process as claimed in claim 7 in which the portion of the composite shell radially of the annular rim is removed by grinding off the material as the composite mold is rotated until the cavity left by the rim section is intersected.

9. A process as claimed in claim 1 in which others of the mold parts are formed by investment casting with the desired edge construction for joinder one with the other.

10. A process as claimed in claim 1 in which the others of the mold parts are formed by compression molding the material with the desired edge construction for joinder one with the other.

11. A process as claimed in claim 1 which the mold parts are joined by an adhesive.

12. The pressure as claimed in claim 3 which includes the steps of separating the patterns and composite shell from the support, subdividing the composite shell and pattern into the separate sections, and then subjecting the sections to the pattern removal step.

13. A process as claimed in claim 1 in which the means joining the separate sections of the mold comprise clamps to hold the parts together.

14. A process as claimed in claim 13 in which the clamps are ceramic clamps.

15. A process as claimed in claim 11 in which the adhesive is a ceramic adhesive.

16. A process as claimed in claim 1 in which other sections of the mold comprise metal sections cored for the passage of coolant therethrough.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,669,177 Dated June 13, 1972

Inventor(s) John E. Ingalls et al.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 8, line 9, change "pressure" to --- process ---.

Signed and sealed this 17th day of October 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

FORM PO-1050 (10-69)

USCOMM-DC 60376-P69
★ U.S. GOVERNMENT PRINTING OFFICE : 1969 O—366-334