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(54) INVESTMENT CASTING METHOD FOR MAKING A DESIRED CASTING

(71) We, KUBOTA LTD., a corporation organised under the laws of Japan of 22, Funade-machi 2-chome, Naniwa-ku, Osaka-shi, Osaka-fu, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

The present invention relates in general to a precision casting method for making a desired casting and, more particularly, to a method of manufacturing a profile member of three-dimensional structure such as a propellor using a precision casting mould.

As is known, precision casting is a process which has been used for many hundreds of years for casting parts of complex shape and recently has come to be employed for casting parts which, even if they have a comparatively simple shape, are required to be cast to precise dimensions, whereby subsequent cleaning or machining processes, which cause loss of expensive material and may also result in an alteration in the properties of at least surface portions of a cast part are rendered unnecessary. Conventionally, in this process, a pattern comprised of wax or polystyrene or of a substance having comparable properties, is formed, either directly or by using a solid master-profile, and the pattern is then dipped in a slurry of refractory material, the pattern being normally sprinkled with sand after being dipped, whereby a refractory coating is produced on the pattern. Back up material such as dry sand is then poured around the pattern, whereby a so-called investment mould is defined in the back-up material, the investment mould is allowed to dry, the wax or other substance defining the pattern is melted and caused to leave the mould, the mould is preheated to a temperature suitable for puring a particular metal or alloy, and the metal is poured and then allowed to solidify, after which the mould is removed.

Since the shape of a cast part is defined by an integral pattern, it is possible to achieve much greater precision than is possible in casting processes in which different portions of a cast part must be defined by separate patterns or parts, and, for this reason, precision or investment casting is commonly used in the aircraft industry, for example. Conventionally, however, it has been found extremely difficult or impossible to produce moulds of sufficient strength to permit the casting of large parts, and in the aircraft and other industries the investment casting process is almost entirely limited to the production of small parts.

For the precision casting of large parts, for example, generator turbine blades having a length of from 40 cm to 130 cm and a weight of from 1 kg to 70 kg, or ship screw propellors having diameters of the order of 200 cm and weights of the order of 250 kg, it has been known to employ a process in which a pair of moulds such as green moulds, gel moulds or ceramic shell moulds are employed over a pattern, then stripped from the pattern, fitted together again, and solidified, i.e., the "shaw process" or a modification thereof. However, in this process, the mould comprises at least two portions which must be fitted in an exact matching relationship and held clamped together, and, apart from the fact that the fitting together of mould halves constitutes an extra working step, it has been found difficult to ensure that the mould halves are exactly fitted together. Cast parts, of which the fitting portions are often produced with over-hand projections, therefore usually require subsequent machining, which results in wastage of material, and with some materials, such as stainless steel, is difficult to effect to a required degree of precision in the machining.

As is known, from hydrodynamic considerations, the thickness of blades of ship screw propellors is varied in the direction of the long axes thereof. If such a propellor is cast by a conventional process, since the green mould employed has a comparatively low heat-resistance, which imposes limits on the temperature to which the mould may be heated during the pouring process, there is liable to be inefficient filling or short-run of the mould by poured metal, particularly when, in order to achieve improved strength and resistance to wear and corrosion, stainless steel is used instead of a copper alloy, in addition to which blowholes or burning stainless steel on the surface of the cast part are liable to occur. Because of these faults, combined with the fact that good dimensional precision of a cast part cannot be guaranteed, as noted above, a cast part always has attached thereto unnecessary metal or other material, which must be removed by machining and increases the cost of manufacture of a propellor.

These disadvantages are not limited to the manufacture of ship propellors, but also apply to the manufacture of silimar large parts having complex shapes, for example, blades of large supercharger turbines, compressors or condensers.

In conventional investment casting processes, because of the properties of the pattern material employed, it is necessary to employ comparatively large and complex injection moulding equipment for injection of thermally fusible material. Except that the pattern of thermally fusible material may be formed manually by engraving art-work, production on an industrial scale may employ a split mould made of a metallic alloy which is used for the casting of a master pattern. In this case, the mould halves must be given a correct finish by a machining or similar process, and then clamped together to define a single mould into which thermally fusible material is injected by an injection moulding machine. However, the use of an injection moulding machine results in increased manufacturing costs, since the split mould defining a required shape must be made extremely strong and able to resist the high-pressure flow of injected thermally fusible material. Also, if the mould cavity is required to contain a core, special measures must be taken to ensure that the core is not moved during forcible injection of thermally fusible material, and the complicated procedures necessary to ensure that the core remains correctly positioned are often the cause of delay in manufacturing processes.

It is accordingly an object of the present invention to provide an improved method for the precision casting of profile members of three-dimensional structure such as propellors, impellers, diffusers, condensers, turbine blades and the like which eliminates problems inherent in conventional casting processes.

It is another object of the invention to provide a method of casting large profile members which does not require the execution of complex casting procedures.

It is a further object of the invention to provide a method for the precision casting of profile members which is not limited to the casting of propellors of particular size or of particular material, and which permits the production of profile members of three-dimensional structure with highly precise as cast dimensions and a smooth casting surface.

It is yet another object of the invention to provide an investment casting method in which the production of investment casting patterns of profile members of three-dimensional structure is easily achieved and the costs of mould-making are comparatively low.

According to one aspect of the present invention we provide an investment casting method which comprises the steps of

(i) preparing a thermally fusible pattern from one of naphthalene and paradichloro-benzene, with or without the addition of at least one vinyl polymer,

(ii) forming a refractory investment enveloping the termally fusible pattern by coating a refractory slurry around said thermally fusible pattern;

(iii) causing a preliminary "melting" of the thermally fusible pattern so as to produce a small gap between said thermally fusible pattern and said refractory investment by dissolving a surface portion of said pattern by means of the vapour of an organic solvent;

(iv) completely melting and removing all the residue of the thermally fusible pattern out of said refractory investment by heating thereof so as to leave the refractory investment having a cavity that has been occupied by said thermally fusible pattern, said cavity having all the details of said thermally fusible pattern, whereby there is provided a rigid ceramic mould of one-piece construction;

(v) preheating said refractory investment constituting said mould within an oven to a temperature approximating to the temperature of the molten metal to be cast (i.e. within the range of from 500°C to 1,100°C);

(vi) pouring molten metal into said mould while the latter is heated to minimize the temperature difference between said mould and said molten metal;

(vii) solidifying said molten metal within said mould; and

(viii) removing the solidified metal out of said mould.

According to another aspect of the present invention we provide an investment casting method, which comprises the steps of:

(i) forming a thermally fusible pattern by melting a thermally fusible substance constituted by at least one of naphthalene and para-dichloro-benzene employed singly or mixed with one or more vinyl copolymers, and pouring said melted substance into a mould at a pouring speed in the range of from 0.1 kg/sec to 5kg/sec.;

(ii) forming a refractory investment around said thermally fusible pattern by repeatedly coating said pattern with a refractory material and then applying thereon refractory flour material;

(iii) effecting a preliminary "melt-out" process to cause the production of a small gap between said thermally fusible pattern and said shell by dissolving a surface portion of said pattern by means of the vapour of an organic solvent;

(iv) effecting a complete "melt-out" process in which said thermally fusible pattern is subjected to heat to effect complete melting and removal thereof from said shell, whereby there is produced a rigid ceramic mould of one-piece construction;

(v) preheating said shell mould to a temperature approximating to the temperature of the molten casting metal (i.e. within the range of from 500°C to 1000°C) and pouring said molten metal into said mould; and

allowing said poured metal to solidify, and then removing said solidified metal from said mould.

According to a feature of the present invention, we provide an investment casting method, which comprises the steps of forming a thermally fusible pattern of a profile member of three-dimensional structure such as a propellor by melting a thermally fusible substance constituted by at least one of naphthalene and paradichlorobenzene employed singly or mixed with one or more vinyl copolymers and pouring said melted substance into a mould at a pouring speed in the range of from 0.1 kg/sec to 5kg/sec; forming a ceramic shell around said pattern by repeatedly coating said pattern with a refractory material and then applying thereon a refractory flour material; effecting a preliminary melt-out process to cause the production of a small gap between said pattern and said shell by dissolving a portion of said pattern by means of the vapour of an oroganic solvent; effecting a complete melt-out process in which said pattern is subjected to heat to effect complete melting and removal thereof from said shell, whereby a shell mould is produced; preheating said shell mould to a temperature close to the temperature of molten metal for forming the profile member such as the propellor, and pouring said molten metal into said mould; and allowing said poured metal to solidify and then removing said solidified metal from said mould. Because of the gap produced in the first effecting stage, stress on, and cracking of, portions of the shell due to expansion of the pattern are avoided in the second effecting stage and there is thereby produced a shell mould permitting the production of the profile member such as the propellor with a good surface finish and precise dimensions.

The manner of achieving these objects and other features of the invention will become apparent from the following full description of the invention when read with reference to the attached drawings, in which like numbers refer to like parts, and

Figure 1 is a cross-sectional view of a thermally fusible pattern defining a ship's screw propellor and coated with a ceramic shell by one form of a precision or investment casting method according to the present invention;

Figure 2 is a cross-sectional view of a heating means for the removal of pattern-defining thermal fusible material and illustrates the stage of preliminary removal of thermally fusible material employed in Figure 1;

Figure 3 is a cross-sectional view similar to Figure 2 and illustrates the stage of main removal of thermally fusible material;

Figure 4 is a cross-sectional view of a mould positioned in readiness for investment after the removal of thermally fusible material therefrom; and

Figure 5 is a cross-sectional view similar to Figure 4, showing a mould defining a ship's screw propellor positioned in a flask immediately prior to pouring.

The description below refers to the casting of a ship's screw propellor, it being understood that the method of the invention is equally applicable to the casting of other types of profile members of three-dimensional structure such as impellers, diffusers, condensers, turbine blades and the like.

In Figure 1, there is shown a hot-melt or thermally fusible pattern 1 which defines a ship's screw propellor or similar part to be cast according to the method of the invention and has coated thereon a ceramic shell 2 of suitable thickness.

The thermally fusible pattern 1 may be made by various known pattern-making methods, such as are employed for example in investment casting or similar processes. Preferably, however, in the method of the invention, there is employed a split mould which is made of gypsum and comprises two halves, and in which portions corresponding to thin portions of a screw propellor master-mould (not shown) define cavities. The proportions of this gypsum mould are chosen with regard to the shrinkage of poured metal and to material which must be removed to produce a finished part.

As a propellor must define a hole to permit the mounting thereof on a drive shaft, such a hole is provided in the propellor-defining pattern, and for reasons which will be apparent later, there may be defined in the master mould a recessed portion corresponding to a shaft hole.

Before the thermally fusible material of the pattern 1 is poured into the central area defined by the two halves of the split mould which are clamped together, there is positioned in the split mould a core 3 which defines a hole for the propellor drive shaft and is provided with a flange 4 at the bottom.

Next, the thermally fusible material, which has a composition described later, and has been rendered fluid by being heated to 85°C, is poured into the split mould. The properties of the thermally fusible material poured into the split mould are such that the use of an injection moulding machine is unnecessary. This does not necessarily mean that an injection moulding machine is absolutely never used according to the method of the invention. However, even for the casting of comparatively large parts, an injection moulding machine, if employed, need have only a simple construction.

A particularly noteworthy feature of the method of the invention is the speed of pouring of the thermally fusible material into the mould. A preferred thermally fusible material employed in the method of the invention is naphthalene. Although such material has many advantages, it has been found that the use thereof in conventional methods leads to surface holes and local porosity in a produced pattern. Our research has shown that the principal cause of such faults is the adherence of steam produced during the pouring process to the wall of the mould. The results of further research and tests have made it clear that this can be avoided by keeping the pouring speed in the range of from 0.1 kg/sec to 5 kg/sec. When fluid material is poured into the mould at a speed greater than 5 kg/sec swirling occurs, and air is entrapped against the mould surface, leading to surface roughness in the finished pattern. In addition to this, there is a tendency for applied release agent to be stripped off, with the result that the separation of the pattern from the mould becomes difficult. On the other hand, if the pouring speed is slower than 0.1 kg/sec, local porosity occurs and, since poured material tends to cool excessively before new material is poured in, step-lines or zones are produced in the surface of the pattern, and the required dimensional precision is not achieved. When the pouring speed is kept in the range of from 0.1 kg/sec, to 5 kg/sec however, patterns with precise dimensions and a smooth surface finish are obtained.

After being poured into the split mould, the thermally fusible material defining the pattern 1 is allowed to solidify and is then removed from the mould. The pattern 1 thus removed still supports the core 3.

The thermally fusible material employed for the pattern may be naphthalene or paradichloro benzene, employed alone or in admixture with polyestyrene resin or polyvinyl acetate. Preferably, however, the total weight of naphthalene is kept in the range of 90 - 99.5% if a mixture of naphthalene and polystyrene resin is employed, in the range of 95-99% if a mixture of naphthalene and a copolymer of vinyl acetate is employed, and in the range of 90-97% if a mixture of naphthalene and polyethylene resin is employed.

The properties of naphthalene and styronaphthalene, i.e., a mixture of naphthalene and polystyrene resin, are shown in Table 1. For comparison, properties of representative conventional waxes are noted in Table 2. Comparing the values in these two tables, it is seen that addition of polystyrene increases bending strength.

TABLE 1

Degree of shrinkage, strength, and coefficient of styronaphthalenes

		Composition		Degree of shrinkage (unconstrained)(%) (for mould forming)	Bending strength (kg/cm^2) (mold forming material)	Linear expansion Coefficient ($\times 10^{-5}$) (20-60°C)
		Naphthalene	Polystyrene resin			
Naphthalene		100	0	0.23	6.8	0.57
Styro-naphthalene	1	99.5	0.5	0.26	20.8	0.87
"	2	99.0	1.0	0.4	25.5	1.02
"	3	97.0	3.0	0.5	31.0	1.56
"	4	95.0	5.0	0.5	34.0	2.71
"	5	90.0	10.0	0.7	37.4	-

TABLE 2

Degree of shrinkage, strength, and coefficient of expansion of representative waxes

	Composition							Degree of shrinkage (unconstrained) (%)		Bending strength (kg/cm^2)	Linear expansion coefficient (x 10^{-5}) (20-40°C)
	Paraffin	Stearin	Ceresin	Brown coal wax	Peat wax	Rosin	Other components	Mould* forming	Paste**	Paste**	
Wax 1	50	50						1.5	0.7-0.8	18-20	42-52
Wax 2	58		25	12			5	1.5	1.05	25-28	"
Wax 3	60			18	15	7		——	1.0-1.18	31-42	"

* Strength of wax when cast moulded

** Strength of wax when injected as a paste by an injection moulding machine

When the thermally fusible pattern 1 is formed, a refractory ceramic shell 2 is formed therearound by repeating the coating and sand-sprinkling processes a set number of times determined with reference to the required strength of the shell 2. For example, coating and sand-sprinkling are alternately repeated 6-7 times if it is required subsequently to cast a screw propellor having a diameter of 400 mm, and 10-12 times if it is required to case a propellor having a diameter of 1,200 mm. The pattern 1 is completely enclosed in the shell 2 except for an opening 10, which, for a propellor pattern, is located on the opposite side of the pattern to the core 3.

Each sand-sprinkling step is designed to strengthen the ceramic shell 2, and the sand employed is suitably a dry sand such as alumina sand or fusible silica, which may be applied in a flow bed tray, or be blown or poured onto the shell 2.

After completion of the requisite number of cycles of coating and sand-sprinkling, the core 3 supported by the pattern 1 is mechanically held, the flange 4 to the shell 2, in order to ensure that the core 3 remains in place after the pattern 1 is subsequently melted out of the shell 2.

After completion of the last coating and sand-sprinkling cycle, preliminary and completion melt-out steps are performed in order to remove the pattern 1 and leave in the shell 2 a central hollow space defining the shape of the propellor it is required to cast. The first of these steps is performed in a preliminary melt-out oven 5 shown in Figure 2, to which reference is now made.

Across a lower portion of the melt-out oven 5 there is provided a horizontally disposed partition board 6, whereby a heating compartment 7 is defined in the lowermost portion of the oven 5. The heating compartment 7 is filled with a fluid medium, such as an oil. An electric heater tube 8 to which power is supplied by a power line 9, is mounted in a lower side-wall portion of the oven 5 and projects into the compartment 7. When power is supplied to the heater tube 8, therefore, the fluid medium in the compartment 7 is heated and the partition board 6 also is heated.

The pattern 1 coated with the shell 2 is held by supports 11 in the oven 5 in such a manner that the uncoated opening 10 thereof faces downwards, whereby melted material of the pattern 1 may fall onto the board 6, on which it forms a layer 12. To dissolve material in the pattern 1 there is supplied to the oven 5 a suitable quantity of organic solvent in the form of an alkene or chloro-hydrocarbon such as 1-1-1 trichloro-ethane (CH_3CCl_3), 1-1-2 trichloro-ethane, ($CHCl{:}CCl_2$), or 1-1-2-2 tetrachloro-ethane ($Cl_2C{:}CCl_2$), for example.

The properties of different solvents employable according to the invention are shown in Table 3.

TABLE 3

	Molecular weight	Boiling point (°C)	Specific heat (2°C)	Specific gravity (4°C)	Vapour density (g/ℓ)	Specific gravity relative to air	Vapour pressure (mmHg.)
CH_3:$CC\ell_3$	133.41	74.0	0.255	1.346	4.69	4.55	100
$CHC\ell$:$CC\ell_2$	131.39	87.1	0.227	1.464	4.45	4.54	57.8
$C\ell_2C$:$CC\ell_2$	165.83	121.2	0.205	1.623	5.13	5.72	14.4

To avoid the necessity of use of an unduly large amount of solvent and also to prevent atmospheric pollution, cooler pipes 13 are provided around the upper portion of the inner wall of the oven 5. Cooling air or other fluid is constantly circulated through the pipes 13 by external conventionally known means (not shown). With this arrangement, as vapour of the solvent rises to the upper portion of the oven 5, it is cooled by the cooler pipes 13 and forms droplets 14, which, since the solvent employed is heavier than air, as indicated in Table 2, run down the inner wall of the oven 5, whereby the solvent is recovered.

The thermally fusible material defining the pattern 1 is melted due to the effect of the latent heat of vaporisation of the solvent and is also dissolved by the vapour of the solvent. At the same time, the vapour of the solvent passes through micro-pores in the ceramic shell 2, and the shell 2 is heated due to the effect of the latent heat of liquefaction of this vapour. It is undesirable to leave the assembly of the pattern 1 and shell 2 for a long time in the oven 5 once vaporization of the solvent has commenced, and after melting of an amount of the thermally fusible material defining the pattern 1 such that a gap 3*a* of several millimetres is defined between the outer surface of the pattern 1 and the inner surface of the sheel 2, the assembly of the pattern 1 and shell 2 is removed from the preliminary melt-out oven 5 and transferred to a complete melt-out oven 15.

Referring now to Figure 3, the pattern and shell assembly is supported in the complete melt-out oven 15 with the opening 10 facing downwards by supports 20 of the same construction as the supports 11 in the melt-out oven 5, and is heated by air at a temperature of 350 - 450°C, which is supplied to the interior of the oven 15 via one or more pipes 17 by a high-pressure burner unit 16. This hot air is preferably directed into the oven 15 in a direction such that is is not blown directly from the pipe or pipes 17 onto the pattern and shell assembly. The top of the oven 15 is closed, and air may leave the oven 15 *via* suitable ducts (not shown).

This two-stage melt-out process in the method of the invention is very advantageous in terms of the maintenance of dimensions in cast parts. Although cracking of the ceramic shell can be avoided in the conventional processes for the melt-out of pattern defining material in which a pattern and shell assembly is immersed in boiling water or in which from the beginning of the process a pattern and shell assembly is heated by an air blast at a temperature in the range of from 350 - 450°C, in the first process, over-long immersion of the assembly results in a weakening of binder material and consequent distortion of the mould, while in the latter process it is difficult to control the path of heat transfer from the boss portion of the propellor to the blade tips or edges, and if the pattern-defining material contains a large addition of polystyrene, i.e., 3% or more, since the material expands before it melts, there may be breakage of large portions of the mould intended to define the blade edges.

With the method of the invention, however, these problems are avoided, since the first stage of the melt-out is accompanied by practically no expansion of pattern-defining material, as it takes place at low temperature and may be short, it being simply necessary to effect the production of a gap 3*a* of the order of 0.5 - 1.0 mm between the pattern-defining material and the ceramic shell interior in order to ensure that thermal expansion has no adverse effects in the subsequent complete melt-out stage.

The melt-out of thermally fusible material in the oven 15 results in the production of a hollow ceramic shell defining a mould 2*a*. To remove any water or residual pattern material which may still adhere to the inner surface of the mould 2*a*, and also to render the mould 2*a* strong and stable, the mould 2*a* is held for a set time at a temperature in the range of from 500 - 1,100°C in a heating furnace 22 such as that shown in Figure 4, to which reference is now made. The furnace 22 defines steel walls which are lined with refractory lining material 23, and in the centre of the lower wall thereof there is provided a mould support stand 24, on which the mould 2*a* is supported with the boss portion thereof underneath and the opening portion thereof facing upwards, the upper surface of the stand 24 being flat in order to ensure stable support of the mould 2*a*. In the support stand 24, there are defined nozzles 27 which provide communication between the interior of the furnace 22 and a high-pressure burner 25, which is provided below the stand 24, exterior to the main body of the furnace 22, and to which gas is supplied by a line 26. Upon actuation of the burner 25, therefore, the mould 2*a* is subjected to a hot blast effecting complete removal therefrom of water and other residual material. In addition to drying the mould 2*a*, the furnace 22 also serves to heat the mould to a temperature as close as possible to the temperature of the molten metal subsequently poured into the mould. For example, the mould 2*a* is held in the furnace 22 for about three hours if it is required to heat the mould to a temperature in the range of from 400°C to 700°C.

After this, the mould 2*a* is placed in a flask 28 such as that shown in Figure 5, with the opening of the mould 2*a* facing upwards and now constituting a sprue 10*a*. Steel shot, chromite sand, zircon sand, or similar dry sand material 29 is packed around the mould 2*a*, only the sprue 10*a* being left projecting above the level of the sand material 29. This projecting portion is suitably wrapped with insulating material 30 made of ceramic fibre, for example.

Under the conditions shown in Figure 5, the mould 2*a* is ready for the pouring of molten metal into it. One of the main advantages of the method of the invention is the fact that the metal poured may be stainless steel. Although recently materials such as aluminium bronze have sometimes been used instead of high tension brass (HB_5C-1), which was previously the main material used for the manufacture of ship propellors, hitherto there has been made avilable no equipment or method permitting the use of stainless steel in an economical manner. This is because, conventionally, use is made of the so-called sweeping mould methods employing CO_2 or green moulds, and problems associated with run and other factors make it necessary to leave 2 - 3 mm to be machined after casting. This is not an excessive amount for conventional copper alloys, which are comparatively cheap and easily machinable, but is excessive for stainless steel which is very difficult to machine, as well as being expensive. The result has been that, in conventional methods, processing costs when propellors are cast in stainless steel are 3 - 5 times higher than when copper alloys are employed. With the method of the invention, however, as noted in greater detail below, extremely good finish and close dimensional tolerances are achieved even when stainless steel is employed for casting propellors, and the amount of material required to be removed subsequent to casting is only of the order of 0.3 mm. In other words, the invention offers the advantage that in terms of overall processing costs there is very little differences between using stainless steel and copper alloys for the manufacture of propellers, i.e., propellors may be easily and economically made of stainless steel, which for this purpose is far superior to copper alloy material.

Examples of suitable types and compositions of stainless steels employed for the manufacture of propellors are given in Table 4 as follows.

TABLE 4

	Material (Code)	C	Si	Mn	Cr	Ni	Mo	Cu
No. 1	KSP-1	0.04	1.4	1.2	18.8	8.5	1.0	-
No. 2	KSP-2	0.05	0.8	0.8	13.0	4.0	0.7	-

Using the method of the invention, there was found to be no difference in casting surface regardless of whether casting was effected by bottom pouring or by top pouring, but the latter type of pouring is preferred since it presents advantages with respect to the preparation of moulds. When a pouring well is employed, there is only a minor amount of inclusion of slag or dross in the finished casting. From the point of view of ease of the casting process, the best process is to use a tea-spout ladle to effect the preliminary pouring and then to effect a top pour.

Subsequent to pouring, castings are allowed to cool, and then risers are cut off and machining or other finishing processes are effected in a known manner, to produce finished propellors.

In contrast with the average value of surface roughness of 50 - 140 μ of propellors cast in conventional sand moulds, the surface roughness of 18-8 stainless steel propellors cast by the method of the invention is very small, and is in the range 5 - 15 μ. Thanks to this, only a small amount of finishing machining is necessary, and the required time and expense for producing a finished propellor are accordingly much less.

Specific examples of the good results obtained by the method of the invention are given in Table 5 just below, which notes the as-cast dimensions of propellors cast by the above-described method.

TABLE 5

Size	Dimensional precision
< 25 mm	<± 0.2 mm
25 - 75 mm	± 0.15 – 0.5 mm
75 - 200 mm	± 0.4 – 1.0 mm
200 - 400 mm	± 0.8 – 1.5 mm
400 - 600 mm	± 1.2 – 2.0 mm
600 - 800 mm	± 1.8 – 2.4 mm
>800 mm	± 0.2 – 0.4 mm

In a further illustration of the advantages of the invention, Table 6 gives a comparison of propellor blade pitch achieved by conventional green mould casting methods and by the method of the invention.

TABLE 6

Distance from shaft centre (mm.)		88.8	106.5	142.0	177.5	213.0	248.5	284.0
Angle of measuring range (°)		30	30	30	30	30	30	30
Radius ratio (R)		0.25	0.3	0.4	0.5	0.6	0.7	0.8
Conventional examples	First blade	650.4	670.8	709.2	724.8	726.0	727.8	731.4
	Second blade	649.8	678.6	708.6	718.8	725.4	730.8	728.4
	Third blade	657.6	693.6	727.8	739.8	745.2	747.0	751.2
	Difference between maximum and minimum	7.8	22.8	19.2	21.0	19.8	23.1	22.8
	Average	652.6		715.2	727.8	732.2	735.2	737.0
(No. 1) KSP-1	First blade	628.8	660.0	682.8	691.2	687.6	687.6	690.0
	Second blade	624.0	644.0	676.8	698.4	688.0	686.4	686.4
	Third blade	627.6	655.2	681.6	686.4	679.2	676.8	681.6
	Difference between maximum and minimum	4.8	16.0	6.0	12.0	9.6	10.6	8.4
	Average	626.8	653.1	680.4	692.0	686.9	683.6	687.2
(No. 2) KSP-2	First blade	631.2	658.2	687.0	699.6	706.2	711.6	700.8
	Second blade	624.0	658.2	688.8	700.2	697.2	692.4	683.4
	Third blade	635.4	669.6	7[illegible].4	712.8	714.0	710.0	707.4
	Difference between maximum and minimum	11.4	11.4	17.4	13.2	16.8	19.2	24.0
	Average	630.2	662.0	693.4	704.2	705.8	704.7	697.2

Ideally, the dimensions for the first to the third blades should be the same, but, in practice, there is inevitably some difference in dimensions or pitch between the blades. As seen from the above table, whereas this difference is large in conventionally cast propellors, it is small in propellors cast by the method of the invention. In other words, the invention makes it possible to manufacture propellors which may be rotated at high speed but are subject to little vibration.

A specific example of the manufacture of a stainless steel propellor according to the method of the invention now follows.

Example

1. Propellor dimensions

Diameter	810 mm
Expanded area ratio	45 %
Weight	15 kg
Number of blades	3

2. Manufacturing stages

a) A gypsum mould was prepared taking into consideration shrinkage and material to be removed to give a finished product of the required dimensions.

b) Naphthalene was melted at a temperature of 85°C, a 1% addition of polystyrene was made thereto and melted therein, and the mixture was poured into the gypsum mould to form a pattern.

c) After the pattern had hardened, it was released from the mould and then allowed to cool to room temperature.

d) The propellor pattern was coated by being dipped in a slurry consisting of silica flour thoroughly mixed in colloidal silica, and while still wet had grains of silica sprinkled thereon, and was then dried. This coating and sand-sprinkling process was repeated 8 times, resulting in the formation on the pattern of a ceramic shell having an average thickness of 6 mm.

e) The pattern coated in this manner was dried for approximately 12 hours and then immersed in a trichloroethylene vapour bath for approximately 15 minutes to effect preliminary melt-off of approximately 1 mm of the outer surface of the pattern, after which the pattern and shell assembly was transferred to a hot air furnace in which it was exposed for approximately 30 minutes to a hot air blast at a temperature of 350°C, so as completely to melt the pattern material and to produce a shell mould.

f) The shell mould thus produced was dried and hardened for approximately 15 minutes in a heating furnace employing high-pressure burners, and was then heated to red heat (approximately 650°C).

g) The heated mould was packed in dry sand, and then 18-8 stainless steel which had been melted in an ultrasonic electric furnace was poured into the mould.

h) After pouring, the cast metal was allowed to cool to room temperature and was then removed from the mould.

3. As-cast dimensional precision

Thickness at two places on each of 20 propellors produced by the above-described process was measured, and it was found that the variation in thickness for the entire sample of 20 propellors was not more than ±0.41 mm and the standard deviation was 0.12. This is as opposed to conventional sand-mould casts for which the variation in thickness is ±1.5 mm or more.

4. Cast surface roughness

Surface roughness was measured at three locations on each of the 20 propellors, and as-cast surface roughness was found to be in the range of 8 - 12 μ, which is much less than the range of 50 - 140 μ achievable by conventional methods.

Although the present invention has been fully described in conjunction with the preferred embodiments thereof and with reference to the accompanying drawings, it is to be noted that various changes and modifications will be apparent to those skilled in the art. Accordingly, such changes and modifications are to be understood as included within the true scope of the present invention as defined by the appended claims.

WHAT WE CLAIM IS:

1. An investment casting method, which comprises the steps of

(i) preparing a thermally fusible pattern from one of naphthalene and paradichlorobenzene, with or without the addition of at least one vinyl polymer,

(ii) forming a refractory investment enveloping the thermally fusible pattern by coating a refractory slurry around said thermally fusible pattern;

(iii) causing a preliminary "melting" of the thermally fusible pattern so as to produce a small gap between said thermally fusible pattern and said refractory investment by dissolving a surface portion of said pattern by means of the vapour of an organic solvent;

(iv) completely melting and removing all the residue of the thermally fusible pattern out of said refractory investment by heating thereof so as to leave the refractory investment having a cavity that has been occupied by said thermally fusible pattern, said cavity having all the details of said thermally fusible pattern, whereby there is provided a rigid ceramic mould of one-piece construction;

(v) preheating said refractory investment constituting said mould within an oven to a temperature approximating to the temperature of the molten metal to be cast (i.e. within the range of from 500 to 1,100°C);

(vi) pouring molten metal into said mould while the latter is heated to minimize the temperature difference between said mould and said molten metal,

(vii) solidifying said molten metal within said mould; and

(viii) removing the solidified metal out of said mould.

2. An investment casting method as claimed in Claim 1, wherein said forming step (ii) is carried out by repeating a predetermined number of times a cycle consisting of dipping the thermally fusible pattern into a bath containing the refractory slurry and subjecting the coated pattern to a sanding process.

3. An investment casting method as claimed in Claim 1 or 2, wherein said preliminary melting step (iii) is carried out by the use of an organic solvent which comprises at least one chlorinated hydrocarbon, said melting of said thermally fusible pattern being achieved in contact with the vapour of said organic solvent and by the effect of latent heat evolved by the vaporized solvent.

4. An investment casting method as claimed in Claim 3, wherein said chlorinated hydrocarbon is 1,1,1-trichloroethane, 1,1,2-trichloroethane or 1,1,2,2-tetrachloroethane.

5. An investment casting method as claimed in any of Claims 1 to 4 wherein said complete melting step (iv) is carried out in an oven at a temperature within the range of from 350°C to 450°C.

6. An investment casting method as claimed in any of Claims 1 to 5, wherein said preheating step (v) is carried out in a furnace at a temperature within the range of from 500 to 1,100°C.

7. An investment casting method as claimed in any of Claims 1 to 6, wherein said vinyl polymers are polystyrene resin, an ethylene-vinyl acetate copolymer and polyethylene resin.

8. An investment casting method, which comprises the steps of:

(i) forming a thermally fusible pattern by melting a thermally fusible substance constituted by at least one of naphthalene and para-dichloro-benzene employed singly or mixed with one or more vinyl copolymers, and pouring said melted substance into a mould at a pouring speed in the range of from 0.1 kg/sec to 5 kg/sec.;

(ii) forming a refractory investment around said thermally fusible pattern by repeatedly coating said pattern with a refractory material and then applying thereon refractory flour material;

(iii) effecting a preliminary "melt-out" process to cause the production of a small gap between said thermally fusible pattern and said shell by dissolving a surface portion of said pattern by means of the vapour of an organic solvent;

(iv) effecting a complete "melt-out" process in which said thermally fusible pattern is subjected to heat to effect complete melting and removal thereof from said shell, whereby there is produced a rigid ceramic mould of one-piece construction;

(v) preheating said shell mould to a temperature approximating to the temperature of the molten casting metal (i.e. writhin the range of from 500°C to 1000°C) and pouring said molten metal into said mould; and

allowing said poured metal to solidify, and then removing said solidified metal from said mould.

9. An investment casting method as claimed in Claim 1 substantially as herein described with reference to the accompanying drawing and/or the specific example.

10. An investment casting method as claimed in Claim 8 substantially as herein described with reference to the accompanying drawing and/or the specific example.

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FIG. 1

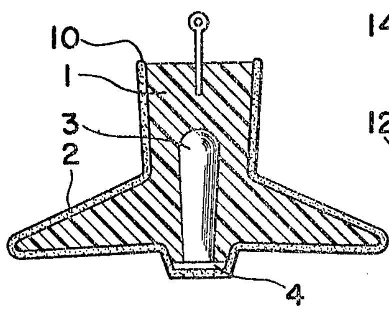

FIG. 2

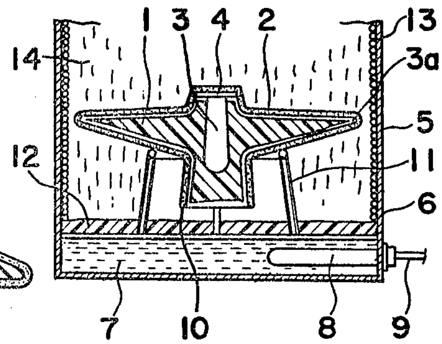

FIG. 3

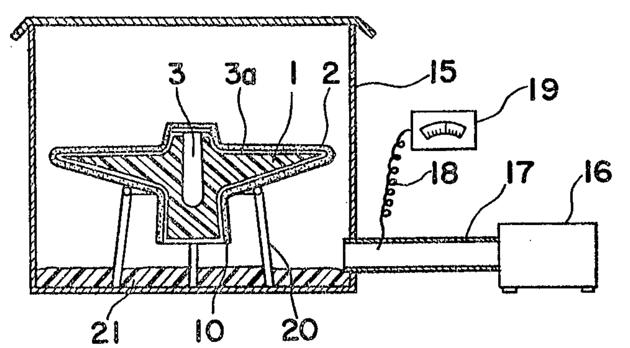

FIG. 4

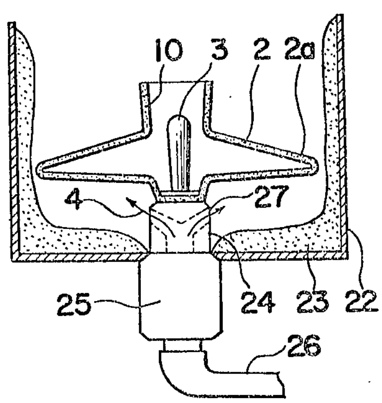

FIG. 5