Precision Casting Method

1. Introduction

Precision casting is one of the oldest and finest process of manufacturing metal parts. It is also known as lost wax, lost pattern, hot investment and investment casting process. It is generally used for casting of valuable metals for which amount of waste materials due to machining should be kept minimum. For ordinary metals and alloys also, this process is competitive for small components if the costs of machining, stamping, etc. are taken into account.

In the precision casting process, a ceramic slurry is applied around a pattern, usually made of wax, and hardened to make a mould. The pattern is removed, usually by heat, and molten alloy is poured into the space formerly occupied by the pattern.

The principal advantages of investment castings are:
1. surface smoothness of 1 to 3 micron, compared to 2 to 4 micron for shell moulding and 5 to 12 micron for sand casting can be obtained.
2. close tolerance in as cast condition is obtained.
3. minimum or no machining is required for completely finished castings.
4. intricate shapes with good reproducibility can be achieved.

Some common disadvantages of the process include:
1. there is a size limitation of the part to be cast; majority of castings produced weigh less than 0.5 kg.
2. patterns is expendable; one pattern is required to produce one casting.
3. use ofd core makes the process more difficult.
4. relatively costly process as compared with other casting processes.

Important applications of the investment process include:
1. to fabricate difficult-to-machine and difficult-to-work alloys into highly complex shapes.
2. for making jewellerys and art castings.
3. in dentistry and surgical implants.
4. to produce milling cutters and other types of tools.

2. Classification

There are two forms of investment casting. One possibility is that the ceramic mixture is poured around the wax in a flask and allowed to harden (the "solid mould" process). In the "ceramic shell" process, the pattern is repeatedly dipped in a ceramic slurry, dusted with refractory, and dried in a repetitive process until a shell of sufficient thickness has been formed around the pattern. Today, the solid mould process is used primarily for jewelry and dental casting; the overwhelming majority of investment castings are made using the ceramic shell process, which is shown in Fig. 1.

3. Steps in Precision Casting Process

Different steps of investment casting (the ceramic shell) process are discussed below.

1. Production of die for making expendable pattern

This is known as the master pattern. Generally die steels or duralumine are used for this purpose which are accurately dimensioned in a tool room. For this purpose double shrinkage of the expendable pattern and of the die should be taken into consideration. Double shrinkage for a brass casting in a lost-wax process can be calculated as follows:

<table>
<thead>
<tr>
<th>Description</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrinkage for wax mixture</td>
<td>1.0 %</td>
</tr>
<tr>
<td>Shrinkage for brass</td>
<td>1.8 %</td>
</tr>
<tr>
<td>Total contraction</td>
<td>2.8 %</td>
</tr>
</tbody>
</table>
Fig. 1.1 Steps in the investment casting process.

But thermal expansion of mould material somewhat compensates the above shrinkage. This is equal to:

- Expansion of mould material during solidification: 0.3 %
- Thermal expansion of mould during pattern elimination heating: 1.0 %
- Total expansion: 1.3 %

Thus a total shrinkage of (2.8 – 1.3) or 1.5 % should be compensated for. This factor is again depends on pouring temperature, rate of pouring, restrictive action of mould geometry, and the rate of cooling.

2. Making of expendable patterns and gating system

From the master pattern, positive replica of the disposable patterns are made. Most commonly used pattern material is wax from which lost wax process has its name. The pattern is formed by injecting pattern wax into a pattern die. Pattern wax is a blend of natural wax modified with fillers, resins, plastics, plasticizers, antioxidants, and dyes. Waxes used for patterns are most often paraffins, vegetable waxes, and microcrystalline waxes. By blending these waxes with each other and adding modifiers as needed, waxes having very specific properties can be produced. The choice of what kind of wax to use depends on the size and shape of the casting to be produced. Additives are used to increase the strength of the wax and to compensate for its shrinkage on cooling.

The patterns are injected at moderately low temperatures and pressures. The temperature and pressure commonly used in wax-injection machines are 70–100 C and 3 MPa respectively. After they harden in the die (which usually occurs in less than a minute for small parts), they are removed from the die and allowed to cool. If they contain preformed cores, they may be x-rayed to be sure that the cores did not fracture during injection. The patterns are inspected visually, die parting lines and the injection feeder are removed, and surface blemishes repaired.

Preformed ceramic cores, if needed, are placed in the pattern die before injection. Alternatively, soluble wax cores may be used instead of ceramic cores; these are dissolved out of the pattern using a weak acid before the slurry is applied. The preformed ceramic cores are primarily made of silica and alumina; they are removed from the castings by dissolving the cores in a caustic solution after casting. The cores are made by injecting the core mixture (usually a slurry of finely divided refractory aggregate in ethyl silicate) into a die. The cores gel in the die and are removed and fired to develop the strength they need to withstand wax injection and metal pouring pressures. They may be very complex, as shown in Fig. 1.2.

Plastic, tin, frozen mercury are also used for making patterns. Plastic patterns are usually made of polystyrene. They require higher mould temperature around 150-350 °C and pressure about 140 MPa. These patterns are more stronger than wax and easy to handle. They are also less expensive and has less thermal co-efficient of expansion. But plastic patterns tend to distort the green investment during melting and parting lines and core flash fins formed are more pronounced than in wax due to higher pressure employed.
In case of frozen mercury pattern, molten mercury is poured into die at -40°C as its melting point is minus 38.83 °C. Parts are joined with gating systems by welding. Low pressure is applied at the joints for that. Wax and plastic patterns are joined with the gating system by heating and partially melting. The gating system is also formed in the same manner as the patterns and attached to the pattern assembly by wax-welding. The assembled clusters are inspected and cleaned by dipping in a solution containing a mild solvent that etches the surface of the pattern so that the slurry adheres to it.

3. Precoating the pattern assembly

The pattern assembly is dipped into a slurry of refractory coating material. The slurries are usually mixtures of fine grained refractory aggregate (usually of 325 mesh or less) in an aqueous silica sol (colloidal silica). The refractory sands may be silica, alumina, gypsum, magnesia, zirconium silicate, or mixture of these. Because of health concerns, ethyl silicate is rarely used as the binder. The common binders used include sodium-potassium silicates, refractory cements, plaster of paris, etc. In addition to the colloidal silica and the aggregate, the slurry may contain a wetting agent, bactericides, antifoaming compounds, and polymers, which are added to give the slurry sufficient green strength, so that it can be re-dipped without being completely dried between dips. Slurry formulations are usually proprietary. The colloidal silica is a colloidal dispersion of virtually spherical particles of silica in water. The average particle size is 7 to 10 nm. Slurries are controlled by adjusting viscosity, temperature, and solids content.

The first slurry, which serves as coating, consists of a fine refractory aggregate, usually more expensive than that used in later dips. This aggregate contacts the molten metal. The pattern cluster is rotated in the dip tank to coat all pattern surfaces. Automated dipping machines assure repeatability of the dipping process. After dipping, the wet assembly is coated by sprinkling it with with a coarser refractory aggregate(40 to 50 mesh). The cluster is dried in ambient air, or heated forced air may be used to accelerate the drying process.

4. Investment of pattern assembly for the production of moulds

The precoated pattern assembly is then invested in the mould. Investment mould may be formed by either solid moulding or shell moulding process.

In solid moulding, the pattern assembly is placed in a metal flask and the investment-moulding mixture is poured around the pattern. The mould material settles by gravity and completely surrounds the pattern as the work table is vibrated. The moulds are then allowed to air-set. A typical investment moulding mixture consists of 91.2% sand, 33.8% water, 6.5% calcium phosphate and 2.3% MgO (300 mesh).

In shell moulding, the precoated pattern assembly is given a second coat by dipping it in a ceramic slurry whose composition will often be similar to that of the first slurry. However, the refractory sand that is applied in this coat is usually more coarse and less expensive than that applied to the first coat. The cluster is dried again, and the process is repeated; this time using a coarser, less expensive refractory in the slurry and sanding operations. A number of dips are given in order to build a shell thickness of the order of 6 to 12 mm. The mould is given a final drying and prepared for the dewaxing operation.

5. Removal of pattern from the investment mould

The patterns are usually removed by melting or burning them out of the mould. The pattern is melted out of the hardened mould by heating the mould in an inverted position at 100 - 200 C (for wax pattern) or 60 - 80
C (for plastic pattern). However, because the pattern material expands about 40 times as much as the mould, care must be taken to avoid cracking the mould during this operation. Wax drain holes are often added to the cluster to provide a path for molten wax to escape during the dewaxing operation. Wax is a poor conductor of heat, so the outer layers of the pattern melt and run out of the mould before the inner parts of the pattern heat enough to expand and crack the mould. One method of dewaxing is to use a steam autoclave. In this method, superheated steam is introduced to the patterns at a pressure of 550 to 620 kPa. The steam penetrates the porous mould and gives up its latent heat of vaporization on the wax surface, which heats the surface very rapidly and causes the part of the wax in contact with the steam to melt. As that wax runs out of the mould, it exposes the wax underneath to the steam, which melts it, and the process continues in this manner. The wax runs into a trough below the moulds and can be recovered and reprocessed. An alternate method of dewaxing is to use a steam autoclave. In this method, the moulds are placed in a furnace at 870 to 1095 °C. The heat melts and burns out the wax. Wax that is not burned falls into a trough below the furnace and can be reclaimed. Flash dewaxing units are equipped with afterburners to eliminate smoke emissions.

After dewaxing, the moulds are fired at 870 to 1095 °C to remove any residual pattern material and other gas-forming materials, like water and alcohol, completely dry the moulds, and sinter the mould ceramic so that it develops the strength it needs during pouring. This operation may be combined with wax removal in flash dewaxing furnaces and with mould preheating prior to pouring. Investment casting moulds are usually preheated prior to pouring to promote complete metal fill in the thin sections typical of investment castings, and to lessen the thermal shock on the moulds when they are filled with molten metal.

To control solidification, the moulds may be wrapped in refractory blankets prior to preheating. The preheat temperature is determined by the alloy being poured and the casting geometry. When the moulds are completely preheated, they are filled with molten metal. Because the amount of metal poured in investment castings is usually small (<20 kg), the moulds may be poured by hand, or they may be clamped to a furnace just large enough to melt the metal for a single mould. As soon as the metal reaches the pouring temperature, the furnace and mould are rapidly inverted, which fills the mould in a smooth even manner.

6. Pouring of metal into the mould

Melting is usually done using prealloyed charges prepared by a custom alloy producer. For some alloys, notably superalloys and titanium alloys, melting, pouring, and solidification is carried out in a vacuum (approximately 10^-3 torr) to protect the alloys from reactions with oxygen. Induction melting is most often used, although gas-fired furnaces may be used for nonferrous alloys, and vacuum-arc remelting is often used for titanium and refractory metal alloys. In dental and jewelry castings, the moulds are often centrifuged during pouring to assure fill of the intricate designs.

The liquid metal is gravity-poured via sprue into the preheated mould. For thin and intricate castings, centrifuging with compressed pressure of 70 KPa or so may be used. The air pressure is applied through the sprue to force-fill the mould cavity. After the casting is solidified, it is removed from the mould and cleaning operations follow cooling of the casting.

4. Postcasting Operations

After casting, the moulds cool, and the ceramic is removed. Clusters are shot blasted, and the casting cut from the sprue. Finishing and inspection operations are similar to those used for sand castings; except, if preformed ceramic cores are used, they must be removed in a caustic bath. If the cores have especially small cross sections, they may be removed in a caustic autoclave, which is pulsed periodically to remove the reaction layer at the core-caustic interface. Caustic (potassium hydroxide) is used to dissolve the silicate binder in the core, allowing the core aggregate material, usually silica and alumina, or an aluminosilicate, to fall out of the casting.