ME 251-Manufacturing Science I

Term Paper- Investment Casting

Content:

Name: S.V. Koushik

Id no.: 11941070

Batch: Mechanical Engineering (2019-2023)

Introduction to Investment Casting:

Casting is a well-known manufacturing process, in which the metal in its molten form, is poured into a mold of the desired shape, which when solidifies results in the casting product. Investment Casting is one of the most important casting processes, which produces many casting products which we encounter in our daily life.

The History of Investment Casting: Investment casting is one of the earliest castings known to mankind. The principles used in this casting can be traced back to 5000 BC when the early man produced rudimentary tools using this method. Many art castings are produced using this. Investment casting gained its popularity during the time of the Second World War since there was a great need for making precision components with complex geometry such as turbine blades for aircraft engines, etc. This was used for scientific purposes for the first time in 1897 to produce dental crowns.

Facts about Investment Casting: Investment casting is also known as **Precision Investment Casting**, as it produces the final products with high accuracy and precision. In this process, we use an expendable pattern to make the mold which makes this process quite costly. The term investment casting is derived from the process "investing", which means "surrounding" the pattern with ceramic (refractory) materials. In this process, we generally use wax as a pattern material and this particular process is called **Lost-Wax Investment Casting**. Apart from wax, we could also use materials such as mercury and plastic as pattern materials. The casting where we use mercury is called **Mercast Process**.

In general, we use Lost-wax Investment Casting to produce components which we use in our daily life. This process gained popularity all over the world in recent times as it is more economical compared to other types of investment casting.

The Description of the Lost-wax Investment Casting:

1. Preparation of Pattern:

In this process, the pattern is prepared with the help of wax. This wax is generally blended with other waxes and materials such as fillers, dyes, resins, and antioxidants so that we could improve the properties of it, as no single wax possesses all the required characteristics. The typical proportion of wax blend includes **waxes (30-70%), resins (20-60%), fillers (0-20%) and other additives (0-5%).**

The waxes such as *paraffin wax, microcrystalline wax, carnauba wax, beeswax* are generally used to get the required amount of fluidity, hardness, etc. While the fillers are used to reduce the solid shrinkage of the wax blende, by usually increasing the melting point of the blende. Some of the common fillers include *Spherical Polystyrene, Spherical articles of Thermosetting Plastic, Hollow Carbon Microspheres*, etc.

The molten wax blende is then injected into a metallic die under a pressure of 2.5MPa. This is often referred to as **Injection Moulding.** The wax gets solidified inside the die producing the required pattern. This pattern is removed and it is kept ready for the pattern assembly.

2. Pattern Assembly:

Many such wax patterns are ejected from the die. These patterns are then joined through a central tree by applying heat to make a single pattern assembly tree. This tree prepared by wax is generally made in such a way that it has the gating system inbuilt in it. Generally, a sprue is connected to all the individual castings. The sprue provides the mounting surface to assemble multiple patterns into a single mold. The sprue also provides the flow path for the molten metal/alloy while filling. This process uses **Gated Pattern**. The assembly tree is fitted with multiple patterns so as to achieve maximum economy.

3. Preparation of Ceramic Mold:

The obtained wax pattern assembly is dipped into the ceramic slurry at a suitable temperature. This ceramic slurry is a blend of **Refractory Powder (60-80%)**, **Liquid Binder (15-30%)**, **Solid Binder (5-10%)**. These ingredients are mixed in the mentioned proportions to improve the quality of slurry. Refractory powders like *Zirconium Silicate, Fused Silica*, *Fused Aluminium oxide* are generally used. Chemicals such as *Ethyl Silicate, Colloidal Silica* are used as liquid binders.

The slurry is coated multiple times to prepare the mold. The slurry which dipped for the first time has a very fine structure so that it can easily get through the details of the grooves and engraving design quite easily. As we increase the number of dippings, we also use the coarser slurry as compared to the previous ones as it builds a thick coating around the wax tree providing the strength for the mold. Between each and every dipping, dry refractory grains such as *Fused Silica or Zircon* are stuccoed on this liquid slurry coating. The slurry has to be dried between every successive dipping so as to increase the strength of the mold. The humidity and temperature are carefully maintained during this mold preparation. This coating thickness depends on various factors such as the shape and mass of the casting product, the binder used, etc. Generally, this thickness ranges from **6 to 15mm.**

4. Dewaxing:

The process of draining out the wax completely from the ceramic shell for a further purpose, i.e. to use it as a mold is known as dewaxing. This is generally carried out in an **autoclave oven**. The ceramic shell containing wax is turned upside down and sent into an autoclave oven. The high-pressure steam ranging from **5.8 to 9.6 bar** is injected into the oven, rapidly raising the temperature of the mold. This results in the removal of wax from the mold.

The molds are dissolved in a hot vapour of a solvent like *Trichloro-ethylene* to remove any wax remnants. This is then heated to a temperature of **100 to 1000°C** in a **flash fire oven**, which melts and burns off the wax. This is done to remove the last traces of the wax. This also helps in a proper filling of molten metal, in the molds having a complex design. The temperature required for pre-heating treatment is decided based on the shape, size, and complexity of the mold. The wax which is removed is refined and used again for this process.

5. Pouring of Molten Metal:

The ceramic mold is generally heated before the molten metal is poured into it, so as to add strength and eliminate the shell cracking. The desired metal is raised above its melting point to obtain its molten form. This molten metal is poured into the mold under gravity and slight pressure. The mold along with the molten metal is kept aside to cool down so that solidification occurs.

6. Shell Knockout:

After the solidification, the metal casting is removed from the shell by breaking it. This process is called knockout. This process is generally carried out by using a **hammer** or a **vibratory table**. The vibratory table produces waves that result in the breakage of the shell. In the case of complex geometry, the ceramic shells may not be completely removed just by shaking it. In this case, the metal casting tree is **sandblasted** so that it is free from minute ceramic particles.

This removal of the shell can also be accomplished through a chemical process, i.e. by using *a caustic solution of either sodium hydroxide or potassium hydroxide* which is heated. But this method is found to cause environmental and health issues. So, this method is almost out of use.

7. Cut-off and Finishing Operations:

The castings are cut-off at the ingates so as to separate the required final product, from the excess material which includes gates and sprue. These cutting operations are done manually by using a **chop-saw, grinding**

wheel, etc. A laser can also be used for this process, but it has very limited applications. The cut-off can also be accomplished by using automation. A **programable cut-off saw** is used in this.

The obtained castings are heat-treated, which helps in improving the properties such as strength. It also relieves stresses in the final casting product. The required surface-finish is given to the casting. This finishes the final casting product, which is free from flaws and is visually appealing.

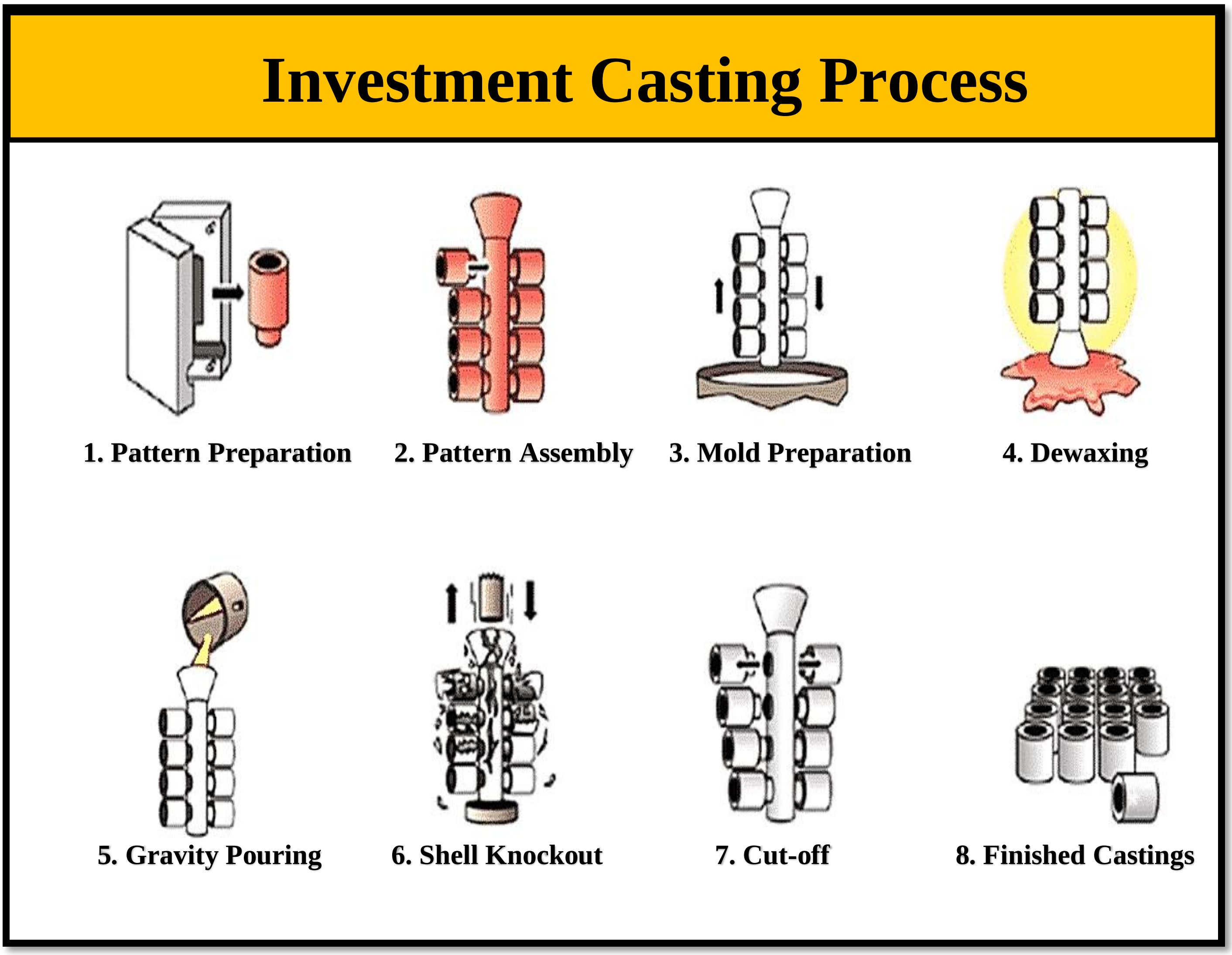

***Fig1.1** The figure shown gives the detailed pictorial representation of the above process*

Image Source: *www.engineeringproductdesign.com*

Types of Investment Casting:

1. Mercast Process:

In Mercast process, mercury is used as the pattern material instead of wax. In this process, the mercury pattern is repeatedly coated with ceramic slurry and stucco. This process is undertaken below **–38°C** as mercury has a very low melting point. It is dried and then heated so as to remove mercury from the ceramic shell. The mold is then filled with molten metal. After solidification, the shell is broken to get the casting product.

The advantage of using mercury is that it doesn't expand while changing its phase to liquid from solid, as in the case of wax. It also gives an excellent surface and very close dimensional tolerance.

The disadvantage of using this is that mercury patterns are quite heavy, which may become a problem while creating a mold. And the entire process must take place at very low temperatures which are very expensive and even difficult to create.

2. Water Glass Investment Casting:

Water Glass Investment Casting is a type of lost wax investment casting. This process is also called **Sodium Silicate Casting.** The difference lies in the binder. Here we use *water glass* $(Na_2(SiO_2)_nO)$ as the binder for the mold preparation. Low-temperature wax is generally used for this process.

The advantage of using this method is that the casting consumes less time compared to silica sol investment casting, as the shell mold is dried through a chemical hardener. Larger castings can be made easily in this process compared to silica sol casting. This is also cheap compared to another investment casting.

The disadvantage of using this is that it is usually applied only for carbon steel. This process does not give better quality, accurate dimensions, and a smooth surface-finish when compared to silica sol investment casting. This results in the further requirement to machine the casting.

3. Silica Sol Investment Casting:

Silica Sol Investment Casting is also a type of lost wax investment casting. The binder generally used in this process is **colloidal silica**. It is made by refractory grains such as *aluminosilicates, alumina used with zircon, and silica*. High-temperature wax is usually used in this process.

The advantage of using this method is that it can be usually applied to many metals and alloys such as carbon steel, stainless steel, high-temperature alloys, etc. This method produces castings of high dimensional accuracy, smooth surface finish, and better quality. Almost nil or negligible casting is required for this.

The disadvantages include, the entire process takes much time as the shell molds are dried naturally at constant temperature and humidity. Larger castings are often difficult to produce using this process. The process is also costly compared to water glass investment casting.

Advantages of Investment Casting:

- This process can be applied to the complete spectrum of alloys and metals in engineering use which include *Steel, Nickel, Cobalt Alloys, Ductile Iron, Titanium Alloys*, etc.
- It can be used to produce very thin and most complex features in casting products ranging from **1 to 1.5mm** thickness as the slurry used for first dipping is prepared by very fine silica grains.
- It offers an excellent surface-finish in the order of **1.5 to 3.2 Ra (microns)** due to the fine structure of the slurry used for initial dipping.
- Obtained final products have a very close dimensional tolerance of about **0.08 to 0.13mm per 25mm** which helps in reducing the requirement of secondary operations for the final product.
- It is mostly applicable to the materials which are difficult to machine and impossible to forge, as it requires almost negligible finishing operations once after the production of the casting product
- Very small castings which include fine details like jewellery can be produced using this.
- The controlled mechanical properties of the casting product can be obtained in this process by taking proper care towards the size and orientation of grain size, and directional solidification.
- No parting lines can be seen, which helps in reducing the machining of obtained casting products.

Disadvantages of Investment Casting:

- The process is expensive as we use expendable patterns. Even there is a large requirement of manpower in the form of labour, which makes it quite costly.
- Huge castings cannot be prepared using this process. The upper limit of the mass of the single casting from a metal tree assembly is about **5 to 10kg.**
- The process is quite slow compared to other casting processes. Generally, it takes about **2 to 7days** to obtain the finished product using investment casting, as the mold nearly requires **8 to 24hours** to dry, between each successive dipping in the slurry.
- Hollow objects are very difficult to cast using this process as it is hard to incorporate the cores inside the ceramic mold.

Applications of Investment Casting:

- Investment casting is majorly used for making the **defence components** that need high dimensional accuracy and a very close tolerance.
- It is used to produce **automotive components**. Many automobile industries use this process to manufacture parts like *gear wheel cassettes, shaft levers, fork fingers, gearbox, and diffusers.*
- The **suspension part** for an F-1 race car and **jet engine diffusers** made of *titanium* are prepared.
- The **pump and valve components** made of *cast iron* are prepared.
- The **lock and its internal mechanisms** are made by investment casting of *carbon steel*.
- The components like **high-speed milling cutter, wheel blades** are generally made by investment casting.
- The **revolver frame** made of *stainless steel* is prepared by this process.
- This process is used to produce the **aerospace components** made of *Al*, *Mg* alloys.
- This process is used for making **dental crowns**.
- This is helpful in producing high precision **surgical instruments** and even have many applications in the medical and orthopaedic industry.
- This process has also a major application in producing the **blades of gas turbines** and other components that are helpful in the power generation and space exploration.

***Fig 1.2** Figure contains different engineering components using investment casting*

Image Source: www.totalmateria.com

***Fig 1.3** Figure shows turbine manufactured by using investment casting*

Image Source: www.totalmateria.com

Conclusion:

The process of **Investment Casting** is invented first to produce art forms and jewellery by the ancient man. But, later with few modifications, investment casting emerged as one of the most used manufacturing processes in our daily life. Now, one could always find a component made of investment casting in their surroundings. This makes it clear that this casting has shown a great impact on our lives for many years.

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