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# COMPETITIVE MANUFACTURING OF 3D COMPLEX METAL PARTS, MADE BY INVESTMENT CASTING

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**Key words**: RP, investment casting, wax pattern, sprue.

**Abstract:** The paper presents the Investment Casting Technology implemented at the University of Cluj-Napoca. Complex 3D shapes from different metals could be cast using the Investment Casting (IC) process, with lowest costs, and less material waste, as compare to the traditional casting methods. There are a large number of applications in low volume production, especially in defense and aerospace industries, for which investment casting may be a lower cost alternative to the traditional methods.

## 1. INTRODUCTION

Investment casting (IC) is a modern technique of metal casting, capable of offering an economical solution to the manufacturing of metal parts with complex shapes, which are difficult or even impossible to realize with the help of classic manufacturing technologies. Parts manufactured by casting are unlimited in form, size and mass. Obtaining them through other processes or technologies is not possible or it would result in overgrowth of the price.

There are many benefits of investment castings. This process is capable of producing precise detail and dimensional accuracy. IC is able to reduce costs in many cases due to reduced machining time and less material waste. [3]

IC is also known as the lost wax process. Metals that are hard to machine or fabricate are good candidates for this process.The process can be used to make parts that cannot be produced by normal manufacturing techniques in various fields: automotive, making jewelry, surgery, dental, aeronautics, statues and art, sports.

General Motors engineers had the mandate to develop a vehicle design that communicated unrivaled performance and style, while reducing weight for fuel efficiency and acceleration. The GM engineers had the mission of reducing the overall weight of the new Corvette. The weight reduction had to be done with no cost penalty, or even better, a cost benefit. Alloy selection is a critical issue in meeting both the mechanical performance requirements and the castability requirements. The cast aluminum brake pedal in Chevrolet Corvette provided the following benefits: weight savings of 72% over the original steel assembly, cost reduction and no additional finishing operations.

Aluminum alloys is one of the most widely cast metallic material. Apart from light weight, the special advantages of aluminum alloys for casting are the relatively low melting temperatures, negligible solubility, and good surface finish that is usually achieved with final products. Most alloy display good fluidity and compositions can be selected with solidification ranges appropriate to particular applications. [5]

In the paper "Application of Rapid Prototyping and Tooling for fast development of patient-specific craniofacial implant: an Investigation Study," the authors showed the need for rapid metal casting technology to achieve cranio-facial implants made of biocompatible materials. [7]

IC technology has tremendous potential in medical applications. RP technologies are also much faster than other manufacturing technologies (CNC), which is a great advantage. Depending on the complexity of the implant during manufacturing can range from several hours to two days. Time and costs are justified especially by comparison with RP technology conventional manufacturing processes, which involve manufacturing time and costs much higher.

## 2. TECHNOLOGICAL PARAMETERS OF THE IC

Casting with easily fusible models allows the obtaining of high precision products, with almost smooth surfaces.

Figure 1 presents the main stages of the rapid metal casting procedure, implemented at TUCN. All the necessary equipment is available within the Department of Manufacturing Engineering.

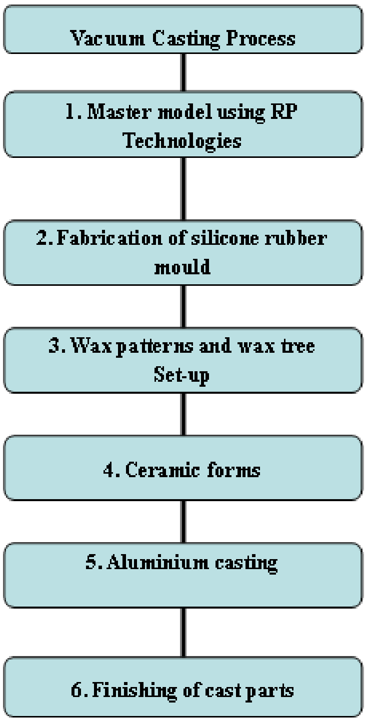


*Fig.1.The main steps for vacuum casting*

Compared with other known casting technologies, vacuum casting is the actual leader in jewel casting manufacturing and different prototyping parts. Conventional IC requires the production of metal tooling for wax injection.

The cost of these metal tools is too high, as compared to the production of the silicone moulds; also the time taken to produce the tools is to long. With RP technologies is easy to produce a model, which will be used in silicone rubber mould fabrication. The silicone rubber moulds can generate multiple wax patterns to produce a number of castings.

Aluminum casting in ceramic forms is a vacuum process, using the INDUTHERM VC 1000 D equipment (figure 2). Indutherm machines are adequate for melting metals at high temperatures. Depending on the type of the equipment, a large scale of metals (aluminum, bronze, iron, etc.) can be cast.

The vacuum casting machine works on the principle of melting the material through induction until the melting point (figure 3). The flowing temperature is controlled manually, depending on the material and the working parameters. Through this method the heat develops in the metal, resulting in a higher heating speed, as compared to the one in the heating oven.

*Fig.2. Investment Casting Equipment, TUCN*

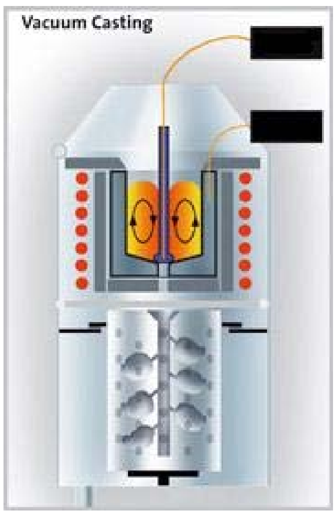


*Fig.3. Melting by induction technology,[8]*

Investment casting tolerances are determined by the size and shape of the casting, as well as by different process factors like: design configuration, type of wax, wax temperature, ceramic mixture, casting temperature, crucible temperature, flask temperature and vacuum pressure.

## 3. SET UP THE WAX TREE

An accurate master model is necessary to produce the max models. This master model could be made in any stimulant material, using one of the existing Rapid Prototyping (RP) technologies. [1]

With the help of the master model the silicone rubber moulds (figure 4) were produced by vacuum casting, using the machine MCP 001 PLC type, available at the TUCN. The creation process of the silicone rubber mould is a vacuum casting process, in order to avoid the risk of getting entrapped air in the mould cavity during casting. The micro geometry duplicating details are excellent and the costs are reasonable. Silicone rubber moulds are suitable to produce wax models (figure 5) which have complex features. Even models with undercuts can be cast in silicone molds having just one splitting line, as the silicone is flexible and allows extracting the cast models. [2]

***Fig.4.Silicon rubber mould, TUCN***

***Fig.5.Wax pattern, TUCN***

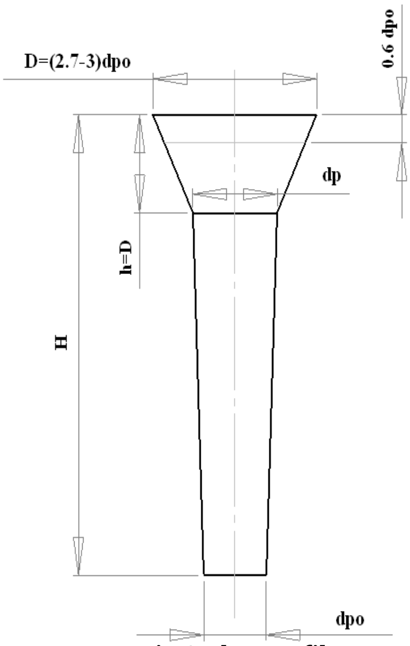


***Fig.6.Flow profile***

Smaller defects on the surface model such as holes caused by incomplete filling are fixed with wax that has the same composition. Patterns are then attached to a central wax stick.

The sprue should have a circular cross section and form a truncated cone with the high base at the top. The diameter is usually 0.25-0.35% of the lower diameter sprue. Optimization of the gate is setting the narrowest area that fills the form in optimal time. Other areas of the elements are defined according to the minimum area on the basis of characteristic reports.

Determine the smallest area, usually the feeder area, then considering the characteristic reports the area of the distribution channel and the sprue is calculated (Figure 6). Gate diameter dp is calculated by the relationship:

$$dp = dpo\sqrt[4]{\frac{H}{h}}$$

Where, D is gate higher base diameter, H is the sprue height, h is the gate height and dpo, the gate riser diameter. Also is necessary to optimize the gate riser taper, c.

$$c = \frac{1}{2}\cdot\frac{dp - dpo}{H - h}\cdot 100$$

The wax tree dimension is another important aspect in the assembly of wax tree. The tree must be sized to fit into the flask. Is necessary a minimum 25 mm at the bottom and 12 mm between the tree parts and the flask walls. Distance between the funnel and the first part must be at least 12 to 15 mm.

The gate is used to supply with liquid metal the whole tree and its volume must ensure a continuous flow field for suppliers. Supply channels may have the shape of a truncated cone. Must have large diameter and length as small, the minimum diameter of the feeder should be about half the maximum diameter, ensuring rapid and complete filling and reduces the porosity curve into the cavity shape.

The advantages of the wax tree assembly are:

- Reduce the consumption of metal, the same gate is used to pour more pieces;
- Reduce the number of shapes and the number of castings.

The disadvantage of the wax tree assembly is that this operation takes a long time, the wax tree has a low mechanical strength and it is asymmetric.

The wax tree was fixed into the flask, in order to pour under vacuum the mixture of ceramic powder and water, using the Investment Mixing unit (KWS EB 20/70). The mixture is poured over the wax tree set in the flask. The ceramic form was dried in the oven and the wax from inside was melted and eliminated out from the cavity. Utilizing the vacuum casting equipment the aluminum is poured into ceramic forms. Progressive gating is important to provide a proper filling of the cavity in the ceramic form.

*Fig.7 Wax tree assembly, TUCN*

*Fig.8. Cast aluminum parts, TUCN*

The surface quality of the part depends on the master model quality, the wax type, the crucible temperature, the vacuum during casting. All these elements are important factors in obtaining good aluminum parts. There are some problems which might appear during the casting process, such as the incomplete fill which appears where the parts are not completely filled with metal during the casting process. This can be caused by the metal temperature (if the metal is too cold it will not have the required fluidity in order to fill the cavities), insufficient vacuum on casting machine (if any of the seals are leaking the effect of the vacuum is diminished leading to an incomplete fill).

## 4. COMPARING INVESTMENT CASTING WITH OTHER CASTING PROCESSES

When considering a casting process, is very important to choose the best one for each application, depending on the technological function.

Sand castings typically have higher costs associated with part price, but lower tooling costs.

Permanent mold casting is often through of as a process somewhere in between sand casting and investment casting.

Investment casting can be used for complex shapes and when accuracy is necessary.

***Table 1***

| Property Name | INVESTMENT CASTING | SAND CASTING | PERMANENT MOLD CASTING |
|---|---|---|---|
| Shapes | Complex shapes, fine details, intricate core sections and thin walls | Very large parts, with complex shapes | Parts having low profile, no cores |
| Part size | Weight: starting from 0.5 grams | Weight: starting from 30 grams | Weight: starting from 50 grams |
| Materials | Aluminum alloys, Titanium, Bronzes, Stainless Steel, Cast Iron, Tool Steel, Precious Metals | Cast Iron, Bronze, Brass Aluminum, Cooper Alloys, Steel | Aluminum, Titanium, Copper, Stainless Steel, Cast Iron Carbon Steel, Alloy Steel |
| Surface finish - Ra (µm) | 1.6 - 3.2 | 6.3 – 12.5 | 3.2 – 6.3 |
| Tolerance (mm) | ±0,127 | ± 0.762 | ± 0.381 |
| Wall thickness (mm) | ≈ 0.5 | ≈ 3 | ≈ 1.5 |
| Quantity (pcs) | 1 – 50 | 1 - 1000 | 1000 - 100000 |
| Lead time | Days | Days | Weeks |
| Advantages | - Can form complex shapes and fine details;<br>- Many material options;<br>- High strength parts;<br>- Very good surface finish and accuracy;<br>- Little need for secondary machining. | - Can produce very large parts with complex shapes;<br>- Many material options;<br>- Low tooling and equipment cost;<br>- Scrap can be recycled;<br>- Short lead time possible;<br>-Least expensive in small quantities;<br>- Least expensive tooling. | - Can form complex shapes;<br>- Good mechanical properties, - Many material options;<br>- Low porosity;<br>- Low labor cost;<br>- Scrap can be recycled;<br>- Ideal for parts having low profile, no cores, in series production |
| Disadvantages | - IC is suitable only for prototypes and small series production<br>- Costs are higher than Sand Casting and Permanent Mold Casting. The process cost is justified through saving in machining time | - Poor material strength;<br>- High porosity possible;<br>- Poor surface finish and tolerance;<br>- Secondary machining often required;<br>- Low production rate;<br>- High labor cost. | - High tooling cost;<br>- Long lead time possible. |
| Applications | Turbine blades, armament parts, pipe fittings, lock parts, hand-tools, jewelry | Engine blocks and manifolds, machine bases, gears, pulleys | Gears, wheels, housings, engine components |

In each case of casting process the surface of the part is independent on variables such as, but not limited to: temperatures, mould surface, tool design and riser capacity.

The investment casting process is based on two variables. The first variable is the complexity of the geometry. We can define geometric complexity as features which increase the difficulty of manufacture such as undercuts, thin walls, increased accuracy, etc., Investment casting is chosen when the geometry of the casting is more complex than can be easily created by other casting methods such as sand casting or permanent mold casting. The second variable is production volume. If the volume is too low, the amortized cost of wax pattern tooling will likely make the casting more expensive than a machined part. Investment casting is only considered when the volume is high enough that the cost of casting drops below the cost of machined parts.

## 5. CONCLUSIONS

In this paper we presented a set of procedure to manufacturing complex parts using the investment casting technologies. Complexity of the parts required a deviation from conventional casting technologies used in industry. Rapid prototyping and Rapid tooling proved to be superior to traditional methods both from an economic and technical standpoint, especially where a small number of parts are required.

The ability to cast low quantities of parts undoubtedly will help to make investment casting a much more attractive alternative to machining in such applications. There are a large number of applications in low volume production, especially in defense and aerospace industries, for which investment casting may be a lower cost alternative to the traditional methods.

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