# IMPROVING THE QUALITY OF THE PARTS MADE BY RAPID METAL CASTING PROCESS

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**ABSTRACT**: The purpose of this article is to present researches for optimizing the vacuum casting process, by dimensioning the feeding system. To manufacture metallic complex parts through investment casting process using wax patterns, with a good quality surface and a high dimensional accuracy it is necessary to optimize the feeding system. In this study, starting from the classic metal casting process a method to calculate the optimal dimensions of the gating system has been proposed, using mathematical relations for the gate, sprue and feeders. Thus we can say that by applying the feeding system dimensioning algorithm and by correcting the master model dimensions with the shrinkage value, we can manufacture complex metal parts through investment casting with a high precision and a good surface accuracy.

**KEY WORDS**: casting, wax patterns, shrinkage.

## 1 INTRODUCTION

The tendencies today on the market refer to the lowering life cycle of products, due to the fact that new products are often launched on the market, new or improved products that replace the existing ones in order to satisfy the client’s needs.

Starting from the necessity to lower a products life cycle a few tendencies from the market can be pointed out: reducing design time for parts, reducing prototype manufacturing time, reducing processing time for the products, increasing the dimensional precision and improving surface quality of the parts, increasing complexity and lowering production costs.

Using the rapid prototyping technologies, known as additive manufacturing technologies, has a real impact on the investment casting process.

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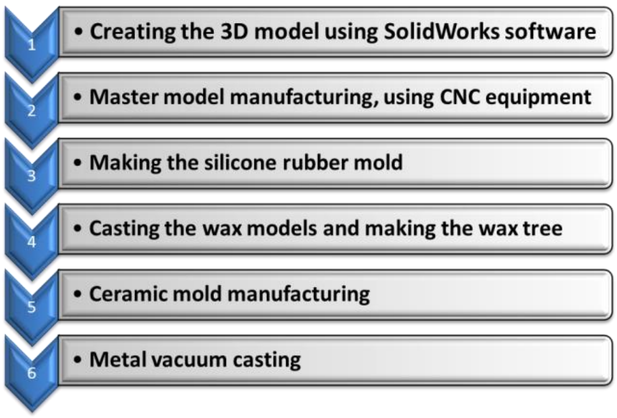
## 2 METHODOLOGY

To achieve the experimental research presented in this paper a CAD model was necessary. To obtain accurate parts, the master model dimensions were increased by shrinkage value calculated using a mathematical model.

The main steps taken to carry out experimental research are:




Vacuum casting process of metal parts with complex shapes involves embedding a master model into a box in which silicone rubber is poured in liquid form.

For this case study the master model was manufactured using a CNC milling equipment in three axes, existing in the Department of Manufacturing Engineering of TUCN.

To remove the air bubbles from inside, the silicone rubber mold is made under vacuum. Once the master model is removed from the mold, the mold is well closed and melted wax is poured into the cavities.

Wax models were manufacture by gravity casting technology using a casting temperature of 80 °C. The mold was preheated at a temperature of 80 °C.

The wax models where used as patterns to manufacture a ceramic form by covering the wax patterns with a fine mixture of ceramic powder and water.

The process of ceramic mold forming also takes place under vacuum, for eliminating the gaps that may appear. The wax patterns are removed from the ceramic form at a temperature of 150°C using an oven. In the owen the ceramic mold is dried, fired and prepared for the metal casting. Finally, the liquid metal alloy is cast into ceramics forms.

After the molten metal has solidified, the ceramic mold is broken away and the metal tree is removed.

## 3 ASPECTS REGARDING THE WAX GATING SYSTEM DESIGN IN VACUUM CASTING PROCESS

The purpose of these studies is to optimize in an efficient way the vacuum casting process, by dimensioning the feeding system. To achieve this optimization a few simulations took place, using dedicated software for metal casting simulation.

The feeding system has a very important role in the metal casting process. The feeding system has the role of a tank that must feed the mold cavity with liquid metal, because the molten metal shrinks in volume during solidification. (Campbell, 2003) The feeders have the role to compensate the shrinkage that takes place when parts solidify, to eliminate the porosities that might appear. (Tavakoli et al., 2009)

The feeding system must assure:

- The correct and complete filling of the cavity, avoiding internal cracks, tensions, etc;
- Correct dimensioning, so that it assures the right amount of liquid alloy, avoiding additional consumption of liquid alloys, especially when using high cost alloys;
- Reduced weight, but resistant enough so it won’t break under its own weight;
- Regulate the cavity filling speed with liquid alloy;
- Guided solidification starting from the inside core walls to the exterior, to avoid solidification of the liquid alloy in the feeder.

Not respecting these conditions may result in the appearance of defects and imperfections on the surfaces of the casted metal parts.

To manufacture metallic complex parts through investment casting process using wax models, with a good quality surface and a high dimensional accuracy it is necessary to optimize the feeding system. (Ravi, 2005)

In this study, starting from the classic metal casting process a method to calculate the optimal dimensions of the gating system has been proposed, proposing mathematical relations for the gate, sprue and feeders.

Based on the studies and researches a set of recommendations has been created to improve the quality characteristics of vacuum casting process using wax models.

The sprue has usually circular cross section as in figure 1.

The minimum diameter of the gate, $d_p$, is calculated using the formula:

$$d_p = d_{po} \sqrt[4]{\frac{H}{h}} \quad (1)$$

The gate diameter, *D*, is calculated using the relation:

$$D = (2.7 \div 3) d_{po} \quad (2)$$

It is recommended that the height of the casting gate, *h*, to be equal to the diameter *D*. The gate and the sprue size depend on the shape and dimension of the part and also on the amount of poured metal.

To calculate the feeding system, a sprue with the following dimensions has been utilized: height *H*=200 mm, the small diameter of the sprue has to be 12 mm, and the large diameter of the sprue is 22 mm.

To determine de exact position of the feeders on the part it is necessary that the part is divided in several simple shapes, with geometry easy to calculate. The module for each shape is calculated.

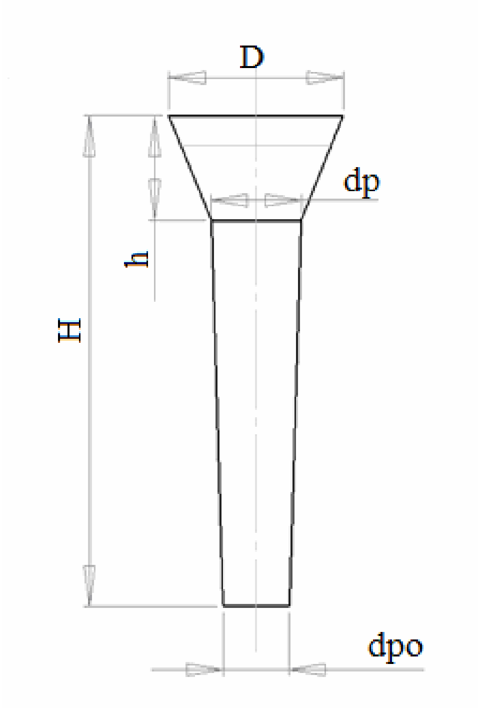



**Figure 1. The gating system**

The module is determined by calculating the following formula between the volume and the cooling surface:

$$M = \frac{V}{S} \quad (3)$$

Where: $M$ is the module value; $V$ is the volume, [cm³] and $S$ is the area, [cm²].

The geometrical shape with the highest module value is the appropriate one to set the feeders on the part. To determine the minimal diameter necessary to feed a part, according to its geometry, it is necessary to determine the feeder module. Researcher John Campbell from Birmingham University, England states that according to the researches, the value of the feeder module has to be at least 1.2 times bigger than the value of the part on which it is positioned to assure a complete filling. (Campbell, 2003)

Using these results obtained using the formula (3), and the geometrical shapes module on which the feeder is set, the feeder module can be calculated with the formula:

$$M_a = M_p \times 1.2 \quad (4)$$

Where: $M_a$ is the feeder module and $M_p$ is the part module.

It is a sure thing that by under dimensioning the feeders, the liquid metal solidifies to early on the feeder, before to get into the cavity, also internal stress and porosity can appear. While over sizing the feeders doesn't have a negative effect on the casting process itself, only on the economical parts.

For the part to be completely filled in a really short time it is recommended to use one or more feeders, for every part, based on their geometry and their dimensions. Using the formula (4) the minimum number of feeders necessary for the complete filling of the part during the casting process is determined:

$$n_a = \frac{L}{d + FD \times T} \quad (5)$$

The parameters used are: $n_a$ represents the number of feeders; $L$ is the linear dimension or the circumference of the casting part, [mm]; $d$ is the temporary diameter of the feeding canals, [mm]; $FD$ is the feeding distance factor (chosen based on the casting alloy) and $T$ is the minimum section of the casted part, [mm]. (Brown, 2003)

Thus, is determined the minimum number of feeders, necessary to completely fill the vacuum cast parts. Using a larger number of feeders doesn't make a worst part quality it only influences the manufacturing costs.

Based on the previous equations, in table 1, the results obtained for the feeders dimensioning are presented.

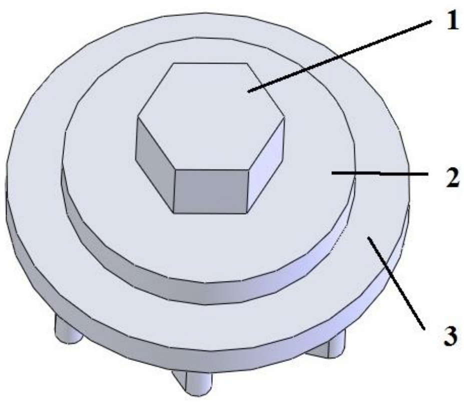



**Table 1. Determining the feeders in vacuum casting process**

| Calculated values | 1 | 2 | 3 |
|---|---|---|---|
| Part module, $M_p$ | 0.45 | 0.2 | 0.24 |
| Feeder module, $M_a$ | 0.54 | - | 0.3 |
| Number of feeders, $n_a$ | 1 | - | 1 |

For building the wax tree, based on the minimum dimensions of the feeding system, obtained through the equations, a feeding system with 2 feeders was chosen, positioned on the part, one for geometrical shape 1 and another one for shape 3 (see table 1). Based on the calculations, shape 1 has the highest value of the module, followed by shape 2.

For shape 1, based on the theoretical results one feeder is necessary, with the minimum diameter of 6 mm. For shape 2 it is necessary also one feeder with the minimum diameter of 3 mm. To assure a complete filling, larger feeders have been chosen, for shape 1 a 9 mm diameter feeder and for shape 2 a 6 mm diameter feeder.

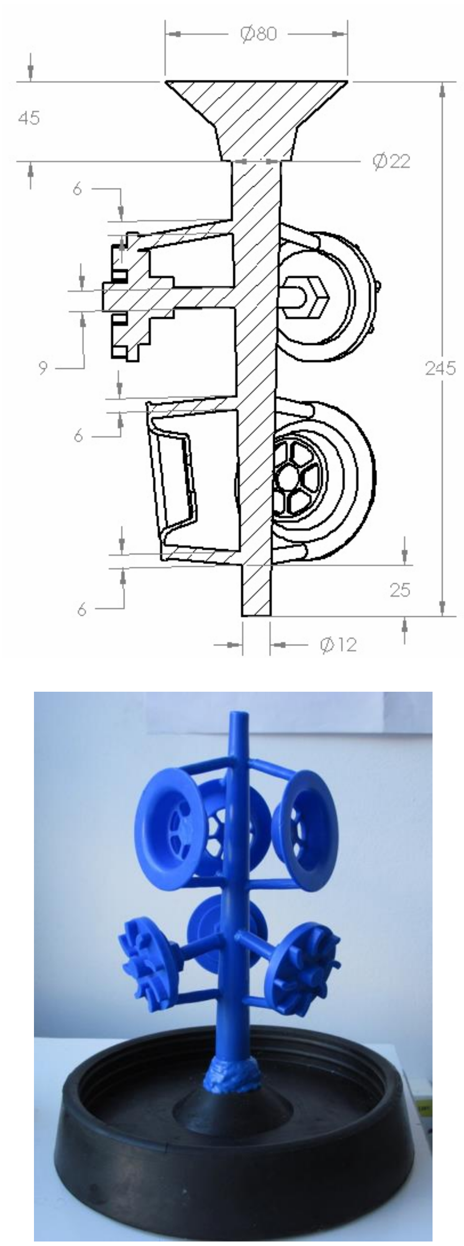



**Figure 2. Wax tree design, made at TUCN**

Before making the wax tree with the suggested dimensions, a simulation was performed with dedicated software to check the correct filling and solidification of the tree with liquid metal and also to check for possible errors or defects.

According to simulation results, the feeding network dimensioning is appropriate for this study. In figure 3 the wax tree is made based on the calculated dimensions.

## 4 EXPERIMENTAL RESEARCH FOR TESTING THE THEORETICAL CONTRIBUTIONS

The vacuum casting equipment used for the experimental research is Indutherm VC 1000D, from INDUTHERM GmbH - Germany.

For calculating the exact amount of aluminum needed to fill the mold cavity, dedicated software for casting simulation process was used. The software proposed 620 g of aluminum, quantity confirmed by the CAD software Solid Works.

The cast aluminum tree, after cooling and solidification was extracted from the ceramic mold with a high pressure water jet. The parts were cut of the tree and the necessary measurements were taken to analyze and validate the results.

**Figure 3. Aluminium cast part, made at TUCN**

The vacuum casting technology using wax models offers exactly the shape and geometry details of the master model.

A wax model is a precise wax design that contains all the details that are desired in the final product. Undesirable details, such as scratch, will also be perfectly reproduced, because lost wax casting produces an extremely precise reproduction of the model.

After measuring the parts, the experimental results are presented in table 2.

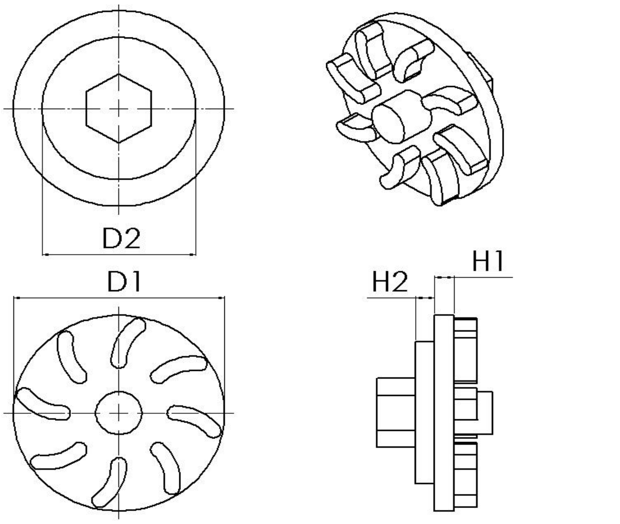



**Figure 4. Dimensions followed in the experiment.**

**Table 2. Experimental results**

| Parameter | Nominal dimension | Master model dimension | Metal part dimension |
|---|---|---|---|
| D1 [mm] | 55 | 56.57 | 55.05 |
| D2 [mm] | 40 | 41.14 | 40.04 |
| H1 [mm] | 5 | 5.14 | 5.02 |
| H2 [mm] | 5 | 5.14 | 5.03 |

To measure these parts two measurement instruments have been utilized with a 0.01 mm precision. The instruments can be found at TUCN. Investment casting is considered to be one of the more accurate casting processes in terms of shape and dimensions.

## 5 RESULTS AND DISCUSSION

To validate the contributions we chose a graphical comparative method. This method is based on a visual comparison, by representing on the same graphic the experimental and calculated results. By analyzing the graphics a visual evaluation has been made in order to validate the experimental study.

According to the results from table 2 and the graphical representation from figure 5, the difference between the nominal dimensions and the experimental dimensions is 0.05 mm.

Thus we can say that by applying the feeding system dimensioning algorithm and by correcting the master model dimensions with the contraction value calculated with a mathematical model, we can manufacture complex metal parts through investment casting with a high precision and a good surface accuracy.

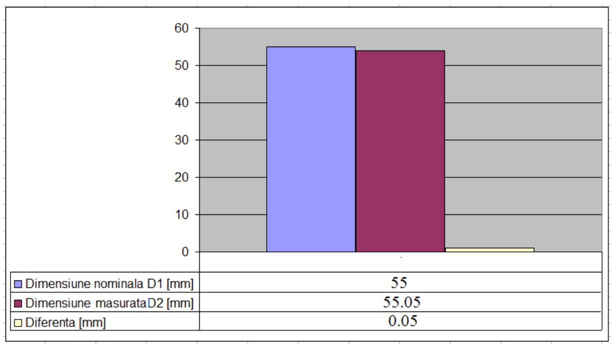



**Figure 5. Graphical comparison between the nominal dimensions and the measured dimensions that took place in this study**

## 6 CONCLUSIONS

In order to optimize the vacuum casting process, using wax models, an experimental study was made to solve one of the most important problems encountered in the lost-wax casting process, the optimization of the wax gating system by determining the optimal dimensions.

Thus calculating the optimal value of the feeding system dimensions and increasing the master model dimensions with the calculated value of the shrinkage, using the mathematical model of the process, complex aluminum parts have been manufactured with a high precision and good quality surface.

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