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CASTING TOOL DESIGN AND COMPUTER-AIDED MANUFACTURING

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Abstract

Designing a casting tool and choosing materials technology parameters calls for special requirements both for workpiece and tool side. After designing the technological steps and procedures I select the cutting tools. Industrial developments take priority in cloud system engineering. I used this system in the casting tool manufacturing process. It is not easy to make a comprehensive and detailed design following technological steps. The allowances and joints were made on the M2L CNC milling machine. The CAM program was made with EdgeCam software. Defining the casting parameters accurately is still a challenge, but in our major it is not the most important. For the future we are planning a most complicated casting tool.

Keywords: *casting, tool, design, CNC, manufacturing.*

1. Casting design

Casting is an ancient method of shaping objects from metals. Three millennium ago, bronze objects had already been cast. The main feature of casting is the variable shape that we can use in making objects with complex geometry. The advantage of this process is that we can produce elements from rigid materials which one can't form plastically. It is applicable both for unique and mass production.

Designing a specific product, the goals are ergonomics, usability and endurance. Several aspects should be taken into consideration in designing a terminal product. Designing a casting tool and choosing materials technology parameters call for special requirements both for workpiece and tool side. When sizing the workpiece and the space that it will take up in the tool mold it is necessary to consider the volume needs and shrinkage factor. After deciding on the right order of the necessary technical steps and procedures, one has to choose the right tools. We calculate the technical parameters for several types of tool based on their catalog values, to make sure that the corresponding tool is inserted into the machine.

1.1. The PLM method

Our goal was to approach the designing phase of the job with modern IT solutions. Designing the finished product

2. Finished product design

During the design process we used a free on-line cloud-based software called Onshape. Cloud-based manufacturing is an Industry 4.0 achievement. Industrial digitization is replacing paper-based design. The 3D design and manufacturing technology design (CAD/CAM) systems are replacing the paper-based design and thus they minimize the paper-based documentation which is required for manufacturing. In industrial companies, any manager can get first-hand information about the processes taking place in the factory, even while traveling thus saving time for the company. It is not necessary for him to be on location, into the plant in order to be aware of processes, or even transitions, stocks, and so on. In the case of Onshape it is available not only for computers, but also as a mobile application. This means that one can have an overview of the design or production process in only a few spare minutes.

The finished product has to be ergonomically suitable, so the angular shape obtained from the sketch had to be rounded off. Sharp corners can injure the user's hand when squeezed or when the product slips from the user's hand. We came up with a solution to this, although its shape allows a stable grip, we round off the outer edges. At first we found it appropriate to use a 3mm radius rounding, but from a technological point of view we had to consider what happens if the depth of the tool shape deviates from the tolerance limit either in a negative or a positive direction. If it deviates in a positive direction, i.e. it becomes larger, an intact band will remain in the molded sample, which will not cause an aesthetic problem, nor will it cause injury. In contrast, if the depth of the mold differs negatively, since the two radiuses converge, there is a possibility to form a sharp edge which must then be removed by post-processing. We decided to take the rounding radius to 2.5 mm and thus avoid manufacturing errors.

3. Casting tool design

Our concept was to make a tool portable for anyone, suitable for simple gravity casting technology with an inlet that is clearly visible. The customer's name is also marked on the tool. For ergonomic reasons, sharp, angled or chamfered edges should be avoided when designing the device. When designing the product, every effort should be made to make the removal of the semi-finished product from the mold as easily as possible, so the mold usually has a taper of 1–3 ° [1]. In our design we replaced the conical surfaces on the side wall of the mold with a 2.5 mm radius rounding; thus, the casting can be easily removed from the mold [2]. The inlet funnel and the location of the pouring must also be determined during the design phase to prevent the forming of inclusions during casting, to make sure that the air in the mold can escape during casting. In this case, we placed both on the wrench side of the finished product. The surface quality of the tool mold must also be specified, Rz = 3.16 roughness was determined. Figure 1 shows a model of the finished product and Figure 2 shows the three-piece mold casting tool formed therefrom. We secured the tool halves with two M8 screws. We solved the positioning of the tools with two pins, which were installed in one tool half with a H7 / m6, while on the other tool half with a H7 / f6 fitting. To make the disassembling of the tool halves after casting, we designed four grooves. These can be fitted with a tool suitable for tensioning.

Because this is a prototype production, the tool was made from non-alloy steel (St52-1, DIN material number 1.0052). This minimizes material costs. During production, high-alloy steels require special tools, which increases production costs.

The tool was converted from Onshape to a para-solid file that includes all surfaces spline-free. This eliminates the need to convert the splines later. The workpiece zero point was the top center of the workpiece. The safety distance was set to 20 mm and all workflows started from there.

Figure 1. *The final product model.*

Figure 2. *The casting tool model.*

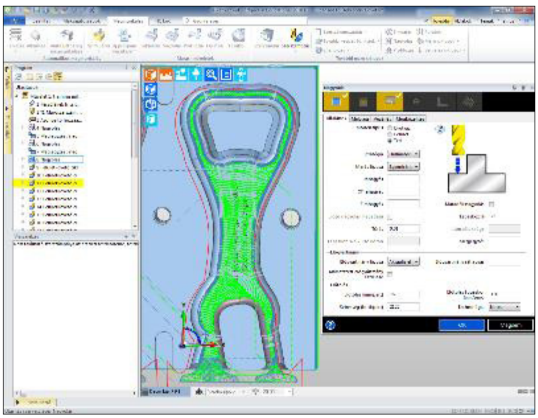

Figure 3. *The waveform milling.*

Boundaries had to be formed in the machining settings, which are marked in red (**Figure 3**). The machining took place at full depth. The behavior of the machine tool was remarkably good. It did not produce excessively severe vibrations, although the casing was slightly noisy. The smoothing only covered the sidewall because, over time, it has been found that, for practical reasons, the waveform pattern acts as an adhesive surface and is an excellent aid to the use of the tool. Surface roughness had to be calculated for smoothing because aluminum can affect the surface defects of the roughened surface and prevent removability. Regarding the surface quality of the tool, a rough surface remains after applying the roughing technology.**[3]**

Calculation of theoretical surface roughness:

$$R_{th} = \sqrt{\frac{{d_1}^2 - {b_r}^2}{2}} \qquad (1)$$

$$\begin{aligned} b_r &= 2 \cdot \sqrt{R_{th} \cdot (d_1 - R_{th})} = \\ &= 2 \cdot \sqrt{0{,}0008 \cdot (6 - 0{,}0008)} = 0{,}1385\ [mm] \end{aligned} \qquad (2)$$

The guideline sidestep value (**Figure 4**) was used for the path generated for smoothing. The result is a very nice, even surface. It is common practice in the tool industry that after machining a flat surface, the workpiece is simply laid on the table of the machine tool and pressed to the table with so-called slippers using a special individual grip. The disadvantage of this is that it can move during milling under high force. Because of the construction of the machine did not set such a limit, it certainly could not move the workpiece out of its place. We placed the slippers relatively close to the milling to prevent a large lever arm touching the workpiece during milling and shifting its position. According to the program, the steps of the machining process took place in the following order:

- Milling of the inlets
- Wrench part
- Device body
- Closure removal part
- 2.5 × 45 ° edge break.

A lacy side can be observed on the mold tool (**Figure 5**). This is due to the wear of the cutter. In this case, a pressed part is formed, and the chips are not worked out at the milled part, but are slightly crumpled, this is called a burr. This is sharp and can easily cause damage to the exposed skin surface. After that, we cleaned the tool mold and then deburred it by hand.

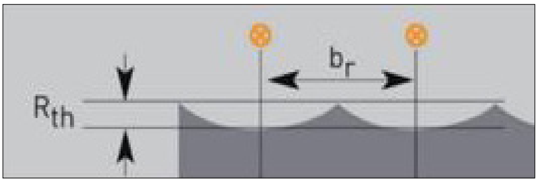

Figure 4. *The surface roughness.*

4. Experiments

Based on its first examination, the melt does not lie completely in the roughly molded part. The slight absorption is located on the side where the bottle opener is (**Figure 6**). The formation of absorption takes place as follows. The outer planes of the product are not stable enough due to unfavorable cooling (as the inner layer retracts during cooling). In our case, this follows from the 6mm wall thickness. Furthermore, absorption may occur due to too slow cooling. Due to the top casting and gravity based technology, the product runs along the cold walls of the tool. It can be seen that it develops farther from the location of the inlet channel.

Based on our second study, hot cracks can be found on several parts of the tool (**Figure 7**). In this case, first and foremost we are dealing with a

Figure 5. *The milled workpiece.*

Figure 6. *Cast product 1.*

fundamentally metallurgical problem. The main reason for the formation of the crystallization crack is deformation. The stresses that occur as a result of the solidification of the melt during the primary crystallization exceed the deformability of the aluminum product.

Based on our third study, the melt does not completely fill the roughed mold part. There is a slight absorption on the neck of the bottle opener and a hot crack in the area of the absorption. Strong absorption is also found on the abutment surface of the opening portion (Figure 8).

Based on our fourth study, we detected a crack and we made a fracture to see how the cracks propagate. From the fracture, we found that the crack was present over the entire cross-section of the material, to varying degrees (Figure 9).

It is also common for such alloys to have a significantly longer time to form various low-melting eutectic, and thus to form a hot crack, due to the large solidus–liquidus heat gap during cooling from the melt state. This problem can be easily remedied by a suitable welding material or already at the design stage by choosing an alloy that can be welded more easily [4]. The tool preheating must be equal on both sides to ensure a proper casting.

Based on our fifth experiment, as a result of the casting, we obtained a usable special tool that met our expectations. The picture shows how the melt fills the mold shape and how it takes on the shape of the roughened surface.

Figure 7. *Crystallization crack.*

Figure 8. *Absorption and hot cracking.*

Figure 9. *Crack and fracture.*

5. Conclusions

We have manufactured a tool that is fully delimited, it fits all boundary conditions and is suitable for production (Figure 10). Several experiments were performed by setting different casting parameters. Finally we managed to cast a usable special tool. Determining the exact casting parameters is still a big challenge, but this topic is not taught as an important issue in our current specialty studies. Our next goal is to make a more sophisticated tool with a larger geometry in the near future.

Figure 10. *Usable finished product.*

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