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The benefits of a conforming cooling systems the molds in injection moulding process

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Abstract

This paper deal with the possibilities and advantage of conformal cooling of the forms. The goal of this paper is a comparison of the impact of conforming and conventional cooling on the quality of plastic products, the distance of the cooling channels and the technological production possibilities. It was developed by assessing the impact of technical and technological parameters on the quality of the plastic product by comparing the length of the production cycle based on cooling duration or individual types of cooling systems. Presented results determine that the use of conforming cooling in the forms for injection molding of plastic has a positive effect on shortening the production cycle and improving dimensional stability of the product.

Keywords: Conformal cooling; conventional cooling; DMLS - direct metal laser sintering

1. Introduction

The technology of mold manufacturing for injection of plastic went over from its beginning to present time through considerable development. From basic NC machining, through CNC - possibilities and recently also through the production of shaped 3D parts. Some of these technologies have been used less and gradually subside to innovative production solutions.

The volume and complexity of molds results in revolutionary innovations to achieve the necessary manufacturability of shaped cavities corresponding to intensity of plastic components.

Thanks to the ever-growing possibilities of machining of the base material and then the final machining by CNC milling, EDM excavating, surface polishing or its profiling it is possible to meet the high demands on the final product.

Injection molding is one of the most shape - variabled and cost effective production methods.

The excellence accuracy is reached by cyclical process in second intervals and in most cases they do not require additional surface treatment.

High reproducibility, mechanical and physical features in the weight range of molds with gram to kilogram is unrivaled solution in every sector. The character of mold as a finished product or as a half-finished product for the needs of the assembly into larger units is another advantage [1]
2. State of the analysis

Design flexibility allows the removal of finishing surface treatments and assembly operations. Mold temperature control system consists of a system of channels and cavities, where suitable fluid flows through, which maintains the temperature of the tempered parts on the required level. The purpose of the temperature control is to reach optimized time of production cycle of injection while maintaining all technological requirements on the production and on the final product.

Tempering is cooling or heating of the form eventually parts of it. With the help of tempering the desired temperature is maintained.

The form tempering affects shrinkage and changes in shape, surface quality and mechanical features of the molds, as well as filling up the form cavity, and the length of the injection cycle time [2].

The movable and fixed form part is tempered independently in the injection molds. To achieve the most efficient heat abstraction, the tempering channels need to be placed as close as possible to shaped form cavity. Flow section is chosen so large that strength of components is not disrupted.

Some plastics are processed at higher temperatures of the form, e.g., PC up to 120 °C. In this case, the heat losses of the form are greater than it is its heating by the melt and it has to be heated. Before the production start it is necessary to warm up the form to operating temperature to avoid thermal shock to the mold.

The goal of tempering is:
- To ensure an even temperature throughout the whole surface of the form cavity.
- To abstract the heat from the form cavity filled with melt that the whole production cycle has an economic length.

Local uneven distribution of form temperature results in increase of dimensional and shaped deviations of molds. However, sometimes different parts of the form are tempered deliberately differently to eliminate shape deformations caused by shrinkage of plastic.

<table>
<thead>
<tr>
<th>Thermoplastic</th>
<th>Melt temperature</th>
<th>Mold temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS</td>
<td>190 - 250</td>
<td>50 - 85</td>
</tr>
<tr>
<td>PA 6</td>
<td>230 - 290</td>
<td>40 - 120</td>
</tr>
<tr>
<td>PC</td>
<td>280 - 320</td>
<td>85 - 120</td>
</tr>
<tr>
<td>PE - HD</td>
<td>180 - 270</td>
<td>20 - 60</td>
</tr>
<tr>
<td>PE - LD</td>
<td>180 - 270</td>
<td>20 - 60</td>
</tr>
<tr>
<td>PMMA</td>
<td>200 - 250</td>
<td>50 - 80</td>
</tr>
<tr>
<td>POM</td>
<td>180 - 220</td>
<td>50 - 120</td>
</tr>
<tr>
<td>PP</td>
<td>170 - 280</td>
<td>20 - 100</td>
</tr>
<tr>
<td>PS</td>
<td>180 - 260</td>
<td>55 - 80</td>
</tr>
</tbody>
</table>

Figure 4. required mold temperature for the various types of plastic materials

2.1 Functions of tempering systems

Heating, eventually cooling of the form to the prescribed temperature depends on the energy balance of the form and its surrounding environment.

The temperature of the forms and especially theirs cavities is not constant during the injection process. Temperature fluctuations should be as small as possible and therefore it is necessary to optimize the tempering process. This means choosing the right size and distribution channels, speed and correct temperature setting of the tempering media.
Several factors are affecting the tempering system, of which it is necessary to mention:
- Type of injected material.
- The size and shape of the mold, eventually the trajectory of the inflow and wall thickness of the mold.
- Requirements for mold precision.
- Material of the form [3].

Thermal and flow features of plastics are decisive in the process of form tempering.

On the cooling process has same impact the thermal conductivity of injectioned materials, fluidity of the plastic and its dependence on the form temperature. The thick-walled molds require intensive cooling, for long inflow trajectory it is necessary on the contrary to increase the temperature of the form.

2.2 The principles in the design of tempering systems

The system of channels with help of tempering facilities supplies or removes the form heat. Their dimensions and layout is chosen for its overall solution. The distance of the channels from function cavity should be optimal.

It is necessary to take into account the sufficient strength and stiffness of the cavity wall. The surface of the tempering channels serves as a transit hub for the area for heat transferred from the form to the tempering medium or vice versa.

It is preferable to use a larger number of smaller channels with small spacing as contrariwise.

The main aim of the designer when designing the tempering channels is to achieve the greatest and at the same time uniform heat transfer between the forming cavities walls and the tempering liquid.

The difference of temperatures at different locations of the forming cavities walls should be as small as possible.

Intense heat dissipation is achieved by forced flow of the tempering liquid in orientated direction [4].

2.3 Arrangement of the tempering channels

When choosing tempering system it is necessary to adhere the following rules:
- To position the channels as close as possible to the shaped part of the form cavity while maintaining a sufficient stiffness.
- To position and to dimension the channels so that the heat was deducted intensively from the places where the mold is in contact with the flow of the injected melt (in areas of inflow).
- To regulate the flow of cooling melt flow so that it flows by cooling from the hottest to the coldest area of the form when heated the flow should be in the opposite direction.
- To choose the ring shape for the channels’ cross section from the production reasons, but it is possible to choose different cross section, for example rectangular or square, or oval.
- Deployment of the channels is proposed with respect to the shape of the mold.
- Channels must pass through an intact form material with a good seal joints.
- The diameter of the channels should not be less than 6 mm otherwise there is a risk of clogging by dirt, lime scale etc.
- Small diameter of the channels requires the use of treated water.
- To design the channels that the individual legs can be connected by hoses in different way and rank.
- Increased cooling action is necessary to ensure near inflow and area of the mouth of the nozzle.

The fig. 5 and 6 shows that the non-conventional methods can not ensure that the cooling channels are in same distance from the shape. This can lead to irregular cooling of the part.

Figure 5. cooling channels  
Figure 6. cross section through cooling channels
3. Solving the problem

3.1 Conformal cooling of injection forms

The cooling circuit designed in the way, that the supply of the cooling fluid is to be delivered to the shortest distance from the mold wall, while it follows the surface shape [5].

Conformal cooling of the forms offers completely new possibilities for form tempering that could be never reached by conventional cooling produced by classical technology.

3.2 DMLS – Direct metal laser sintering

DLMS technology – with direct laser sintering of metals disposes 1. prešovská nástrojáreň Ltd. For the production of conforming cooling the machine EOSINT M 280 (Fig. 9) is used.

It is a cutting-edge technology based on innovative principle DMLS (Direct Metal Laser Sintering) by direct laser sintering of metals that was developed and patented by EOS. The production of components through additive manufacturing - fully automatically, and without tools and based on 3D CAD data that is imported into the machine.

For this purpose it is equipped with a 400W fiber laser which melts the layers of fine metal powder and builds the product in 0.05 mm layers. Constant monitoring of the manufacturing process ensures that all components are manufactured in excellent quality and reproducibility.
3.3 Preparation of the technology and production of plunger – by DMLS technology

In the production of components using DMLS technology, it is necessary to follow certain steps and rules in order to achieve the desired quality as shapes, as well as material properties.

Material specification at the end of the sintering process:
- Material hardness: 33-37 HRC
- Surface roughness Ra 4 - 6.5 microns
- Accuracy, in comparison with 0.05 - 0.1 mm
- Material strength: 1100 MPa ± 100 MPa

If it is necessary to achieve greater strength or hardness, it is possible after completion of the sintering process to implement the process of material curing in the hardening furnace.

The process is carried out at the temperature of 490 °C for 6 hours and then part cools at room temperature. After this process the finishing operations are necessary.

Specification of the material after heat treatment:
- Material hardness: 50-54 HRC
- Changing the measurements of parts during heat treatment 0.08%
- Material strength: 1950MPa ± 100 Mpa

After evaluating the possibilities of production and evaluation of the model adjustments are necessary. Allowance for machining is about 0.5 mm - 0.8 mm, but the size is optional.

The fundamental step for the work is to define the position of the part in space so that all its components remain in the positive values of grid system. + x + y + z.

Consequently, the inclination of the part is then determined. Such as determining position, as well the inclination depends on the experience of technology engineer. Orientation is especially important for the proper application of metal dust and elimination the machine collision. The correct orientation also prevents dropping of the walls in the sintering process.

Saving at the lean state is best to eliminate stress during setting of the material.
Subsequent generation and modeling of the side rests and support assurance for the wall part at its sintering.

Once a draft is created, then the whole process is executed by the PSW software that is machine control system. With help of this software the individual layers are calculated, that in turn are sintered, as well as the location of components on the platform (desktop machine), time calculation etc. The production space of the machine: 250x250x310 mm, where 310 mm is a maximum height of the component, that can be produced.
The coated layers are in the height of 0.04 to 0.05 mm, depending on the required product quality.
For the production of metal powder MS1 is used, which supplier is EOS (machine manufacturer).
The powder has a grain size 0.008 mm. The density of the material is 8.1 g / cm³, which as compared to the plain steel 7.85 g / cm³ is a minimum difference.
Once a draft of sintered components is created, it is possible to verify the time at which the panel is created, but this is the indicative figure.
The production time depends mainly on the height and volume of the part, but as a rule the higher the component, the longer the production time.
The joint formed between the platform and components is removed mechanically, by cutting.
The shaped parts of the form for the mold pressing of the button have been created by this particular technology.
Values in the production of one facial part:
Build time: 20 hours 30 minutes
Dust weight: 2.034 kg
The part was then heat treated and machined using EDM technology and high-speed milling.
The time calculation using the software PSW.

The calculation of part’s weight is done using the formula: \( \text{volume} / 1000000 \times 8.1 \)
Calculation for a specific part:

\[(251108,844/1000000) \times 8,1 = 2,034\text{kg}\]

4. Results

Cooling in the form for the production of the button has been produced by conventional method and for the production of a duplicate instrument DMLS technology was used. With this option, it is possible to compare the injection molding cycle time, shape deformations and visual perfection.

The plastic parts was molded from ABS.

Discovered benefits received with injection molding the button:
- Elimination of deformation of shape and compliance of roundness of product

Using the process capability index.

Graph. 1 shows the stability of the process for conventional cooling when CPK is 1.522 compared to the graph no. 2 which shows the stability of the process using a conforming cooling circuit when the Cpk 1.968.
- Reduced cooling time up to 20%
  Conventional cooling time 18 seconds as compare with conformal cooling time 14 seconds

- Shortening production cycle time up to 10%
  Conventional cooling cycle time 36 seconds, compared to the achieved conformity with a cycle time thanks to cooling, which was able to stabilize a process for the 32 second cycle time.
5. Conclusion

The presented investigations about the benefits of conformal cooling made by modern DMLS technology - direct metal laser sintering lead to several conclusions. In general it can be said, that by optimizing the cooling cycle according to plastic part and not only production possibilities it is possible to use absolute freedom when designing the shape of cooling circuit. Thanks to this possibility are homogenous heat removal from the injection form cavity and it comes to reduction of shape deformation of the mould. Great part of it is time reduction injection molding production of plastic parts itself as the cooling cycle is shortened and so is total production cycle. The influence conform cooling leads to general cost reduction thanks to saving production time. Thus time saved can be used for production of other components. Conformal cooling has been designed especially for geometrically complex molds to remove the heat generated in areas where this is not possible with the conventional methods.

References


Graph 4. compare injection molding cycle time