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Numerical Optimisation of Mould and Injection Moulding Process: Case Study

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Abstract: The paper presents the optimisation of mould for injection moulding as well as injection moulding process parameters using numerical computer simulation in the Moldex3D software package. The optimisation process will be applied to a specific moulded part – branching terminal block – and an already manufactured mould. The paper includes evaluation of the existing mould for injection moulding designed and manufactured without application of numerical simulation of injection moulding process. According to the shortcomings found out in evaluation process, by application of numerical simulation of injection moulding process, the optimisation of the mould design was conducted in several stages to achieve as optimal as possible moulded part quality and injection moulding process parameters without dramatic changes in already manufactured mould.

Keywords: injection moulding; Moldex3D; mould for injection moulding; numerical computer simulation; optimisation

1 INTRODUCTION

Today with the injection moulding process, moulded parts of very complex geometries are made from polymer materials with very different properties. The market puts high demands on the quality of such products, and at the same time demands for a shorter cycle of injection moulding, and lower prices of moulds and moulded parts. To meet those requirements, computer simulation using CAE (*Computer Aided Engineering*) software is necessary [1, 2]. Computer simulation can be powerful tool for prediction certain defects and problems related to the mould and moulded part design, as well as injection moulding parameters [1, 3]. Observed defects and problems can be eliminated in the early stages of development and design. This is much more economical and efficient compared to solving them when the mould is already made [1, 2]. Computer simulation also can be applied to optimise the mould design, the quality of the moulded part and injection moulding process parameters [4, 5]. The paper presents a case study of optimisation of already made mould for polymer product - branching terminal block [6]. By applying a computer simulation using the Moldex3D software package on the existing condition, an insight into the causes of errors in the mould design was obtained, and optimisation steps are evaluated.

2 ANALYSIS OF EXISTING SYSTEM FOR INJECTION MOULDING

2.1 Moulded Part and Mould [6]

Branching terminal block is used for breaking the insulation of insulated conductors in a bundle as well as for connecting the cores of the house connection cable and public lighting. The branching terminal block assembly consists of 7 basic elements, and the subject of the optimisation in this paper is the upper and lower part of the clamp housing made by injection moulding.

The material of the clamp housing is polyamide PA6-GF30 reinforced with 30% glass fibres, resistant to UV (*Ultraviolet*) radiation and weather conditions. The approximate dimensions of the upper part of the clamp housing are 57 × 55 × 35 mm, and the lower part of the housing is 50 × 50 × 25 mm. Fig. 1 shows the CAD (*Computer Aided Design*) models of the upper and lower parts of the clamp housing.

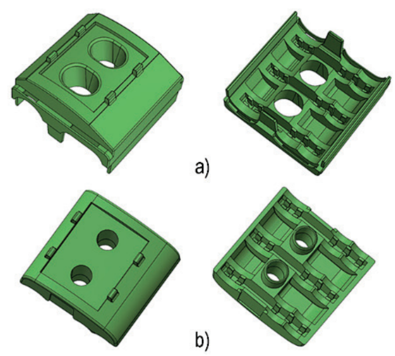

Figure 1 Branching terminal block housing: a) upper part, b) lower part [6]

Already made mould is a two-cavity mould. One mould cavity is used for moulding the upper part, and the other for moulding the lower part of the branching terminal block. Mould cavities are made using the dies in a fixed mould plate, and cores in a movable mould plate. Fig. 2 shows a movable and a fixed mould plate.

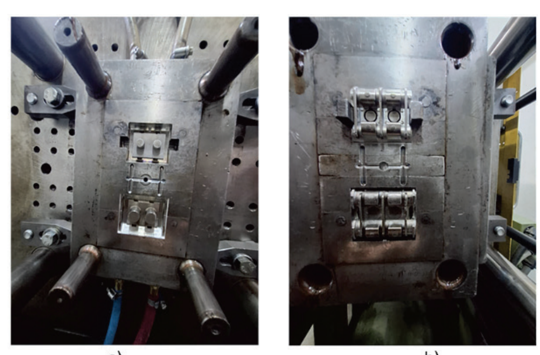

Figure 2 Mould for branching terminal block: a) fixed side, b) movable side [6]

The runner system (Fig. 3) is designed as a cold runner system with a nozzle height of 60 mm and an initial diameter of 3 mm, a main runner channels with a circular cross-section and 5 mm in diameter and four manifold channels with a circular cross-section and 4 mm in diameter. Each mould cavity is connected to runner system by means of the tunnel gates. The tunnel gate is made in a fixed moulding plate at an angle of 35° in relation to the parting plane, with an end diameter of 1 mm and a length of 3,2 mm.

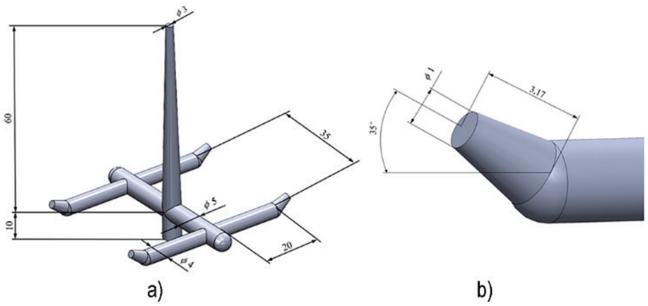

Figure 3 Mould runner system: a) runner system elements, b) tunnel gate [6]

The resulting tempering system (Fig. 4) consists of two cooling channels of circular cross-section with a diameter of 6 mm, spaced 170 mm apart, on each of the moulding plates. The cooling channels are not connected to each other, i.e. each of them has a separate inlet and outlet of the tempering medium outside the mould.

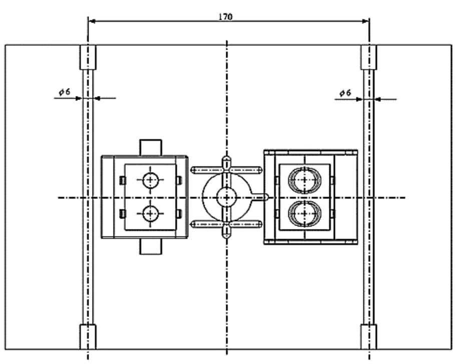

Figure 4 Mould cooling channels (movable mould plate) [6]

2.2 Definition of Simulation Model

For the computer simulation of the injection moulding process, the software Moldex3D was used. When applying computer simulation, the first step is to define the simulation model and generate a finite elements mesh on all simulation model elements [7]: moulded parts, runner system, cooling channels and mould plates (Fig. 5).

The next step is to define the moulded part material selected from the database of the Moldex3D – BASF Ultramid B3EG6. In the next step, within the Process Wizard module it is necessary to define the basic parameters of the injection moulding process: select the type of injection moulding machine for simulation, define the parameters of the filling phase and the packing pressure, and define the parameters of the cooling phase. Fig. 6 shows the menu for determining the parameters of the cooling phase.

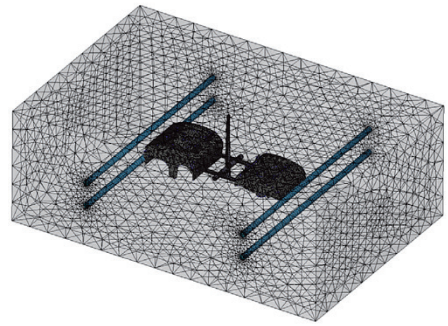

Figure 5 Simulation model with finite elements mesh [6]

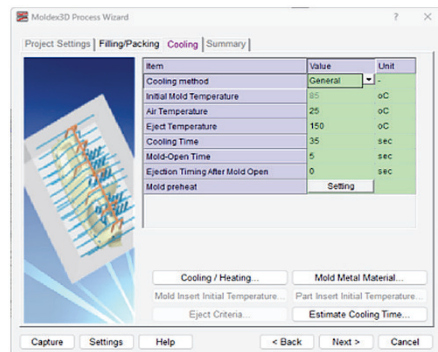

Figure 6 Process Wizard – cooling phase parameters definition [6]

2.3 Main Results of Injection Moulding Simulation [6]

Analysing the results of the previously described computer simulation, several problematic phenomena were observed during the injection moulding cycle, namely:

- uneven mould cavities filling
- appearance of air pockets
- inefficient cooling channel configuration
- moulded part warpage.

Since the existing mould consists of two mould cavities that are used to shape two different moulded parts, and which are connected by the same configuration of the runner system, it is expected that there will be uneven filling of the mould cavities. Fig. 7 shows this problem during the injection phase at the point of switching to packing pressure.

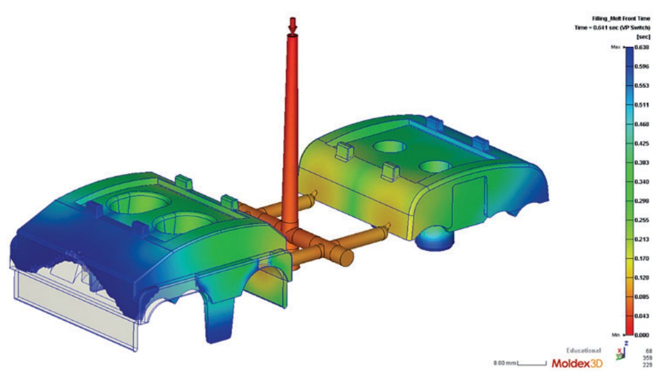

Figure 7 Uneven filling of mould cavities [6]

At the Fig. 7, it can be clearly seen that the mould cavity for the lower part of the housing is completely filled with polymer melt, while this is not the case with the mould cavity for the upper part of the housing. The unfilled part of the mould cavity will be filled with melt during the packing pressure phase. This will cause uneven cooling times of the moulded parts, i.e. while the unfilled part will be filled by the melt, the remaining parts will already begin to cool down. The goal is that at the end of the injection phase, the mould cavities are uniformly filled with polymer melt above 90 % in volume.

The appearance of air pockets occurs due to an inadequately implemented system for venting the mould cavities. Air remains trapped inside the mould cavities after mould closing, which is why the melt fails to completely fill the mould cavity. In addition to this phenomenon, there is a possibility of creating burns on the moulded parts in the form of black dots due to overheated air that remains trapped inside the mould cavity. The venting system of the existing mould is very poor, and the result is the presence of the black spots that on the mould plates, caused by the gasification of the polymer material.

Computer simulation allows the determination of the potential places of air pockets, which are shown in Fig. 8 for the existing mould.

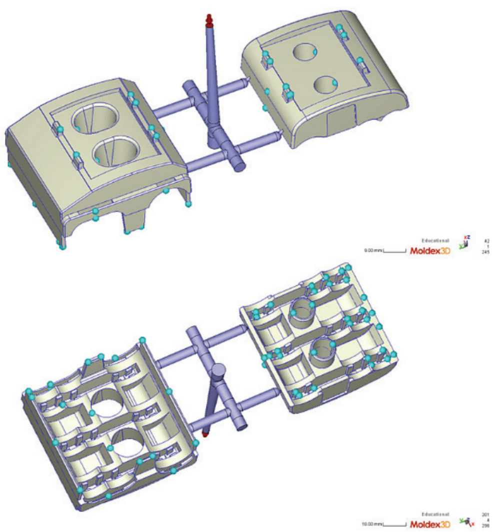

Figure 8 Air pockets - simulation results [6]

The configuration of the cooling channel described in chapter 2.1 is inefficient, and it should be kept in mind that the recommended temperature of the mould cavity wall is 85 °C (for specific polymer material), which is quite a high temperature. Therefore the removal of heat from the moulded parts is very slow and inefficient. The obtained results related to the efficiency of the applied cooling channels are shown in Fig. 9 (max. efficiency – 12,9 %).

Additional problem that needs to be eliminated during cooling phase is the reduction of rather large percentage of melt remained at the end of the cooling phase of injection moulding cycle. The current melt percentage is 3,5 % and is shown in Fig. 10.

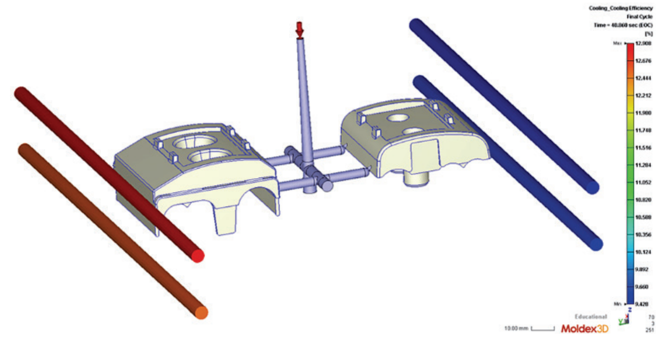

Figure 9 Cooling channels efficiency [6]

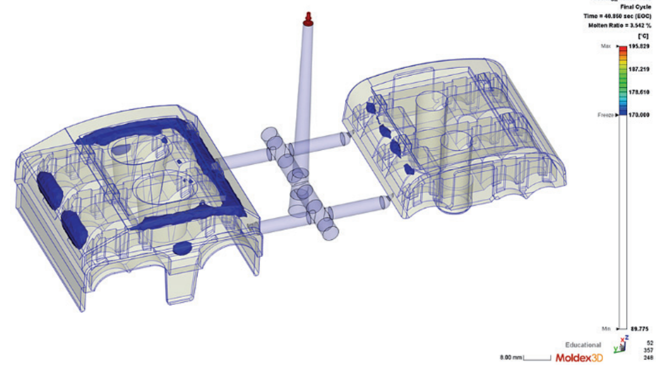

Figure 10 Percentage of unsolidified melt at the end of cooling phase [6]

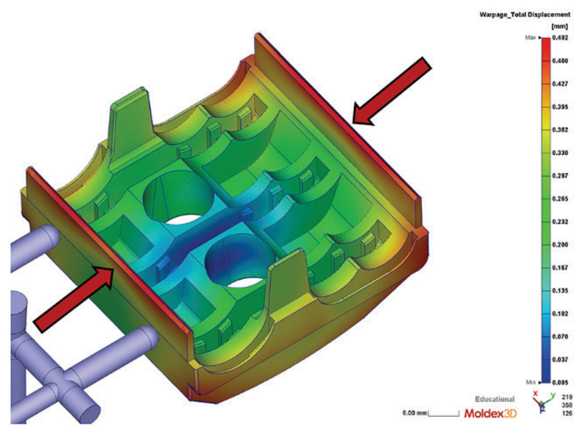

Figure 11 Warpage of the moulded upper part - simulation [6]

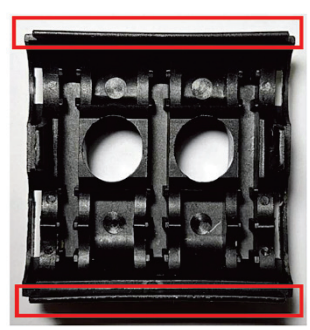

Figure 12 Warpage of the moulded part - real upper part [6]

The remaining of the melt at the end of the cooling phase causes increased warpage of the moulded part after ejection from the mould, because in these zones it was not possible to reach the temperature of shape stability. Figs. 11 and 12 show the results of the simulation of warpage of the moulded part and the actual moulded part deformation.

3 OPTIMISATION OF THE EXISTING MOULD FOR INJECTION MOULDING [6]

Based on the observed phenomena, optimisation was carried out in several steps, namely:

- optimisation of the mould runner system
- optimisation of the mould cooling system
- optimisation of the mould cavity venting system.

3.1 Optimisation of the Mould Runner System [6]

The goal of this optimisation step is to balance the filling of both mould cavities. As the optimisation is carried out on an already made mould, there are certain limitations in the optimisation possibilities. Therefore, the segments of the runner system that delivers polymer melt to the cavity for housing upper part are increased.

When optimising that part of the runner system, the dimensions of the runner channels were kept at the existing dimensions (4 mm diameter), while the final diameter of the gate was increased from 1,0 mm to 1,3 mm. The results of this optimisation step are shown in Fig. 13.

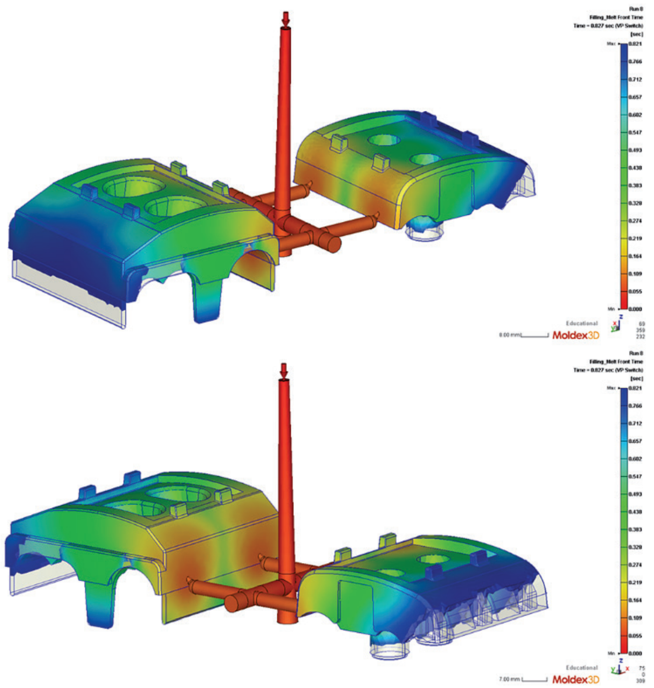

Figure 13 Results of optimisation of mould runner system [6]

Fig. 13 shows a more uniform filling of both mould cavities compared to the initial state. It can be concluded that more than 90 % filling of both mould cavities is achieved at the point of switching to packing pressure, which was the goal of this optimisation phase.

3.2 Optimisation of the Mould Tempering System [6]

Based on the existing cooling channels, it was assumed that increasing the channel diameter would not be enough, i.e. that adding new cooling channels also have to be considered. The first step was to define a new layout of cooling channels. Adding new cooling channels to the movable mould plate is not feasible due to the collision with ejector locations, so the only option left is to add cooling channels to the fixed mould plate. Fig. 14 shows the layout of additional cooling channels.

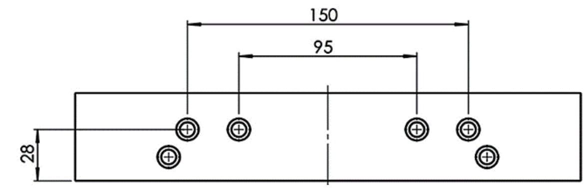

Figure 14 Adding new cooling channels (fixed mould plate) [6]

Fig. 14 shows that four new tempering channels were added at distance of 95 mm and 150 mm, and at a height of 28 mm from the mould parting plane. During the first iteration of optimising the tempering system, the initial channel diameter of 6 mm was maintained. Fig. 15 represents the efficiency of the cooling channel after the first phase of optimisation the tempering system.

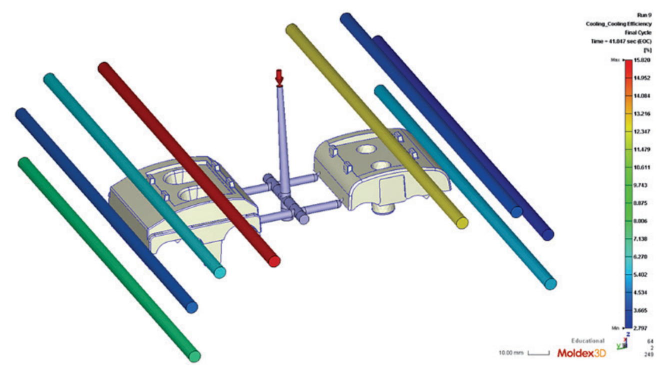

Figure 15 Cooling efficiency optimisation - first iteration [6]

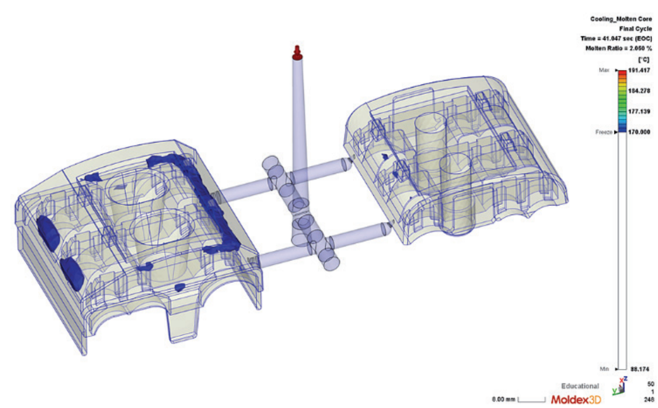

Figure 16 Percentage of unsolidified melt – first iteration [6]

According to the simulation results, it can be concluded that the efficiency of the subsequently added channels is not significantly higher compared to the existing ones (max.

15,8 %), it is about 3 % difference. In this case, remaining percentage of the melt at the end of the cooling phase is shown in Fig. 16.

Based on the previous figure, it can be concluded that the percentage of melt has decreased to 2,06 %, which is less than the current percentage of 3,54 %. From Fig. 16, the largest decrease in the percentage of melt occurred in the mould cavity that forms the upper part of the clamp housing, in the area below the subsequently added cooling channel. As for the mould cavity of the lower part there is a small percentage of the remaining melt that can be ignored.

The second optimisation iteration of the tempering system includes adding new cooling channels as well as an increase their diameter from 6 mm to 8 mm. In that case the efficiency of the channels remained the same as in the first optimisation iteration. Fig. 17 shows the results of the analysis of the unsolidified melt at the end of the cooling phase in the second optimisation iteration for the cooling system. The results show again that there are no significant improvements with the increase cooling channels diameter. The percentage of the melt after the second optimisation iteration is 1,99 %, which is only 0,07 % less compared to the first optimisation iteration.

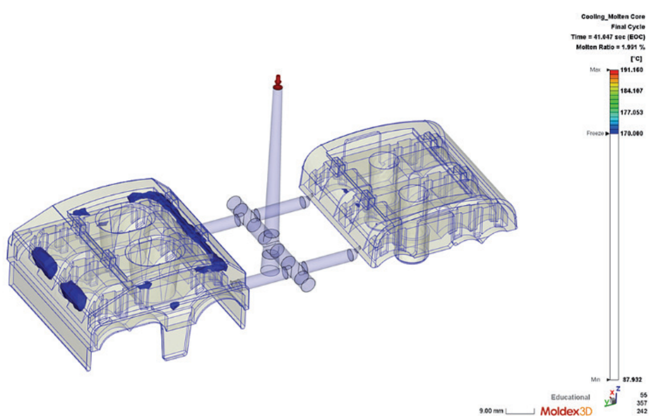

Figure 17 Percentage of unsolidified melt – second iteration [6]

Through the iteration phases of optimising the tempering system, it was concluded that it would be preferably to add additional cooling channels, and that it is enough to remain with the existing diameter of 6 mm. The ideal case would be to add more cooling channels in movable mould side, but this is not feasible due to the mould configuration. On the movable mould plate, the space is limited with the positions of the ejectors, while on the fixed mould plate care must be taken regarding the subsequent placement of the inserts for better venting of the mould cavity.

After optimising the mould runner system and cooling channels, the warpage of the part remains almost the same as in case of the initial mould. Maximal warpage is even 0,01 mm larger (compared to Fig. 11), but the warpage distribution is much more suitable because it is now accumulated in the corners of the upper part of the terminal block housing, which does not affect the assembly with lower part (Fig. 18).

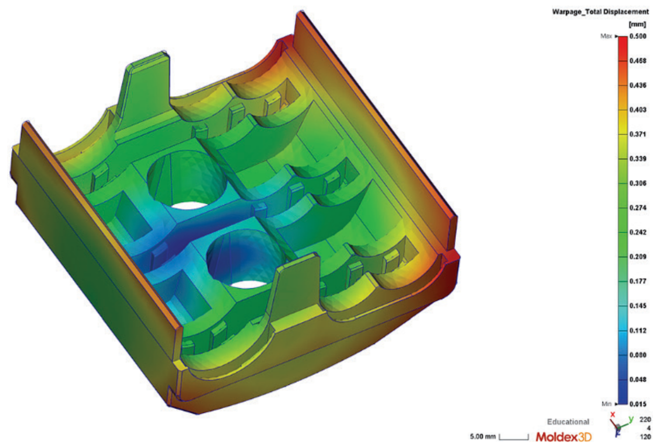

Figure 18 Optimised warpage distribution – upper part [6]

3.3 Optimisation of Mould Cavity Venting System [6]

Based on the results shown in Fig. 8, the following solutions can be suggested. As for venting in the fixed mould plate, it is possible to make inserts for cavity venting. Fig. 19 shows a CAD model of the venting insert, and the locations of these inserts in the fixed moulding plate (view from the parting plane).

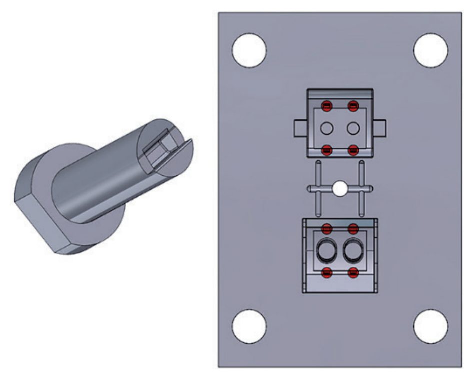

Figure 19 Air venting insert CAD model and locations at mould parting plane [6]

The arrangement of the venting mould inserts in relation to the cooling channels (avoiding collisions) is shown in Fig. 20.

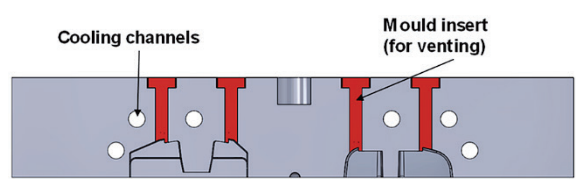

Figure 20 Arrangement of venting inserts in fixed mould plate [6]

Venting in the assembly of the movable mould plate can be performed using the ejectors. In this case, the ejectors need to be shaped as shown in Fig. 21 – grinded tangentially from 0,01 to 0,05 mm to allow the air but prevent the melt to escape from cavity. Shaping the ejectors in this way does not represent a major change in the mould, but it can improve the venting of the mould cavities.

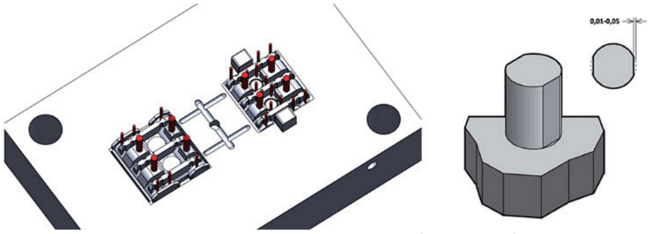

Figure 21 Tangential ejector shaping for venting [6]

4 CONCLUSIONS

The aim of this paper was to present the application of computer simulation of the injection moulding process in order to optimise the existing process and mould. Based on the obtained simulation results, several problematic phenomena were observed during the process, i.e. non-uniform filling of mould cavities, a large number of potential places of formation of air pockets and inefficient configuration of the cooling channels.

In the first step, the runner system was optimised to achieve a uniform filling of both mould cavities. After the optimisation of the runner system, the optimisation of the tempering system continued with the aim of finding a more efficient configuration of the cooling channels. When defining the additional cooling channels, it was necessary to pay attention to the possible subsequent installation of inserts for venting the mould cavity, and accordingly leave enough free space. The obtained results showed that the idea of introducing additional channels was justified, but without the need to increase the channel diameter. By introducing additional channels, the percentage of melt within the moulded part at the end of the cooling process was reduced by 3,54 %, which improvement compared to the initial injection moulding process.

Finally, within the optimisation of the venting system based on the obtained simulation results, two modifications of the existing mould were suggested: production of mould inserts in a fixed mould plate and tangential grinding the ejectors in movable mould plate.

Optimisations of the mould runner and cooling system have the positive impact also on the warpage of the moulded part in form of more suitable distribution over the upper housing part geometry.

As part of this paper, computer simulation was used to detect existing problems on the manufactured mould, and in addition, it was used to find solutions so that the previously described problems could be eliminated as effectively as possible. Within the virtual environment, it is very easy to change the dimensions of the runner system and/or processing parameters and try different combinations. In this specific case, as the simulation was performed for already made mould, its design limitations were considered. Therefore, the injection moulding simulation results are only sub-optimal.

Acknowledgements

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