HEAT TRANSFER MONITORING OF INJECTION MOLD

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Presented article is focused on heat transfer in injection mold, which is designated for plastic parts production. As experimental part was selected two components injection mold with hybrid cooling. Molds cooling system was in two variants: conventional and conformal cooling. In subsequence three variants of cooling were simulated. First variant contained conventional cooling system manufactured by drilling technology. Second variant was designed with conformal cooling system which copies shape of the molding. Third variant consisted of conventional and conformal cooling combined. Simulation procedure was performed in simulation software ANSYS. Temperature presets for injected molding was set according to used material Makrolon 2805. Heat transfer between individual parts of mold was evaluated using individual probes.

KEYWORDS

injection mold, conformal cooling, plastics molding, simulation, heat transfer

1 INTRODUCTION

Injection moulding is one of the most exploited industrial processes in the production of plastic parts. Its success relies on the high capability to produce 3D shapes at higher rates than, for example, blow moulding. The basic principle of injection moulding is that a solid polymer is molten and injected into a cavity inside a mould; which is then cooled and the part ejected from the machine [Tusek 2015].

The main phases in an injection moulding process therefore involve filling, cooling and ejection. The cost-efficiency of the process is dependent on the time spent in the moulding cycle. Correspondingly, the cooling phase is the most significant step amongst the three, it determines the rate at which the parts are produced. As in most modern industries, time and costs are strongly linked. The longer is the time to produce parts the more are the costs [Manas 2014].

A reduction in the time spent on cooling the part before its is ejected would drastically increase the production rate, hence reduce costs. It is therefore important to understand and thereby optimise the heat transfer processes within a typical moulding process efficiently. Historically, this has been achieved by creating several straight holes inside the mould (core and cavity) and forcing a cooler liquid to circulate and conduct the excess heat away so the part can be easily ejected [Behalek 2011].

The methods used for producing these holes rely on the conventional machining process such as drilling. However this simple technology can only create straight holes and so the main problem is the incapability of producing complicated contour-like channels or anything vaguely in 3D space. An alternative method that provides a cooling system that 'conforms' to the shape of the part in the core, cavity or both has been proposed [Valicek 2015]. This method utilises a contour-like channel, constructed as close as possible to the surface of the mould to increase the heat absorption away from the molten plastic. This ensures that the part is cooled uniformly as well as more efficiently [Solfronk 2015].

Growing numbers of injection molders are discovering the advantages of using conformal cooling channels that follow the shape of the cavity and core, reach hot spots, and promote temperature uniformity in the plastic materials being molded [Michalik 2014].

These molders are seeing striking results: shortened cycle times, improved plastic part quality, and above all cost reductions. Even so, many manufacturers, some of them with long experience in the industry, still think conformal cooling is too difficult and too expensive. They think these things because both used to be true [Stejskal 2013].

If conformal cooling is implemented with little or no engineering analysis, you can expect to get a 10% reduction in injection mold cycle time. However, by performing more engineering analysis - such as flow analysis, computational fluid dynamics (CFD), and finite-element analysis (FEA) - a better quality mold and more cycle reduction can be achieved [Dulebova 2014].

A typical cycle-time reduction range for a properly engineered, conformally cooled mold is 20 % to 40 %. If little or no engineering analysis is done, you risk premature mold failure or lack of performance because of poor design elements or incorrect assumptions that were not identified and corrected before mold manufacture [Svetlik 2013].

2 APPLICATION OF LOADS

Analyze purposes was selected two components injection mold. Complex design of mold and cooling system solutions were provided by 1st Presov Tool Making Company Ltd., which deals with developing and production of the mold. Injection mold is provided with hybrid tempering system, while top side has conformal (Fig. 1) cooling and bottom side has conventional cooling (Fig. 2).

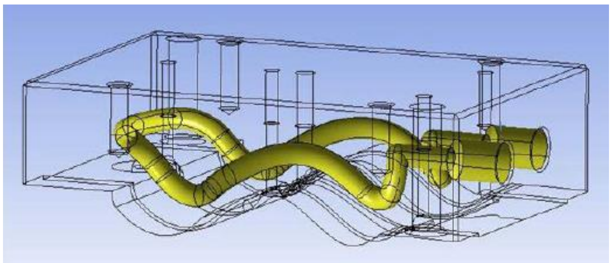

Figure 1. Top side of injection mold with conformal cooling

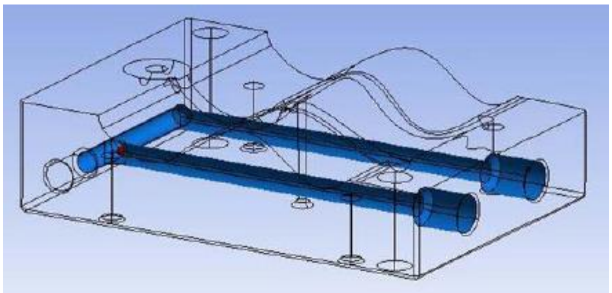

Figure 2. Bottom side of injection mold with conventional cooling

There are more ways of approach to apply load in ANSYS environment. In simulation is possible to apply loads on volumes, surfaces, lines and points or on finite elements mesh. For thermal analyze were applied loads on model surface of mold.

On following figures (Fig. 3) are shown defined loads for simulation: conventional (A), conformal (B), temperature of injected molding (C) and periphery of mold surface (D). Conformal and conventional cooling was defined as load on surface of cooling system cavity, preset Convection. Tempering medium for simulation was set as water on 40 °C and heat transfer coefficient (film coefficient) for selected medium. Preset "temperature" was applied on mold surface while initial temperature was set 280 °C and final temperature 130 °C, what represents ejecting temperature for injected polymer. Environment temperature was applied on exterior of mold at value 25 °C as convention and heat transfer coefficient was selected for medium "air".

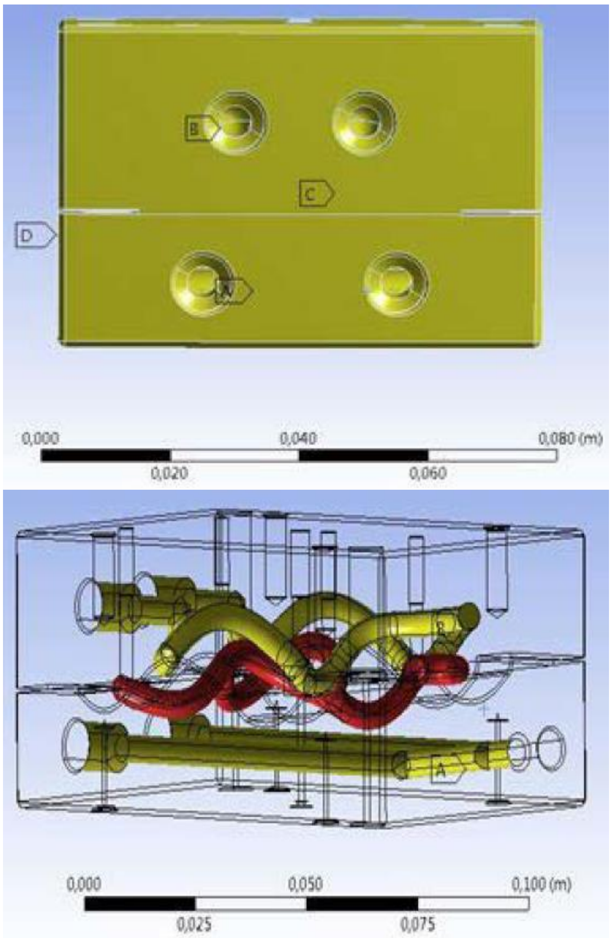

Figure 3. Graphical representations of applied loads

Simulations were performed as follows:

- Conventional cooling – in this case all cooling circuits will be active except of conformal. Analysis settings will be set at time 40 seconds.
- Conformal cooling – in this case will be all loads active except of conventional circuit. Analysis settings will be set on 36 seconds.
- Combined cooling – in this case all loads will be active, for both conformal and conventional circuits. Analysis settings will be set on 32 seconds.

Time presets are obtained from simulations held in software Autodesk Simulation Moldflow.

3 SIMULATION RESULTS

Sequentially will be presented and graphically displayed heat transfers in injection mold for three variants: conventional, conformal and subsequently conformal cooling. In results will be comparison and evaluation of tempering systems.

3.1 *Conventional cooling*

Fig. 4 shows the heat transfer in the mold separation plane with situated conformal cooling, which was not active during the simulation. In the part where is divided injection is in each case in the middle of a red zone of the probe at about 125 °C. In this area accumulates the most heat and with distance to the edge the temperature quickly decreases.

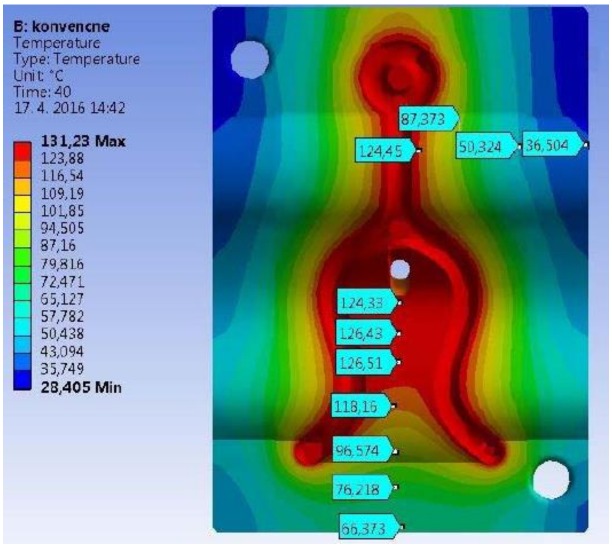

Figure 4. View of temperature distribution for conventional cooling – view 1

Fig. 5 shows cut of the mold by median plane, where is monitored top and side part of the mold, where are situated probes on the surface and inside the mold (view in cut).

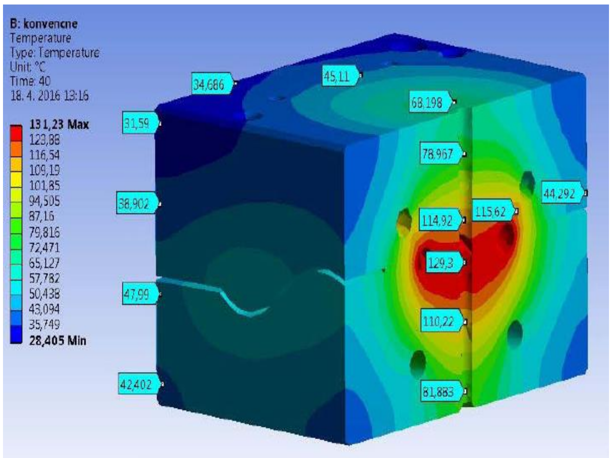

Figure 5. View of temperature distribution for conventional cooling – cut 1

Fig. 6 shows the mold form of one quarter of the cut from the back of the mold form. In this view can be seen that the temperature at the top of the mold despite the fact that there is no active cooling - is lower. This phenomenon is probably due to the fact that the volume of the upper mold is larger, and thus is also influenced by passive cooling.

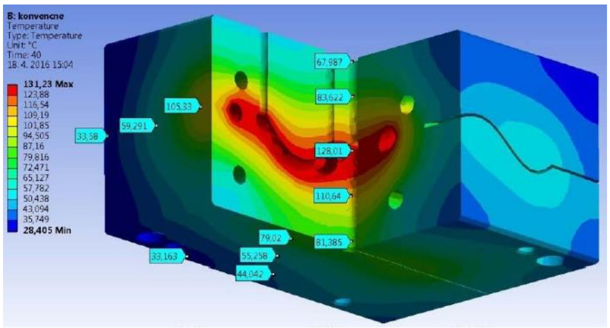

Figure 6. View of temperature distribution for conventional cooling – cut 2

3.2 *Conformal cooling*

Compared with the results of a previous simulation of the conventional cooling can be seen that area where the model is divided into two symmetrical parts, the area where is accumulated the heat (Fig. 7).

According temperature zones not in whole area in the red zone as in conventional cooling but a significant reduction in temperature in the area was not monitored and the average reduction was about 2 °C.

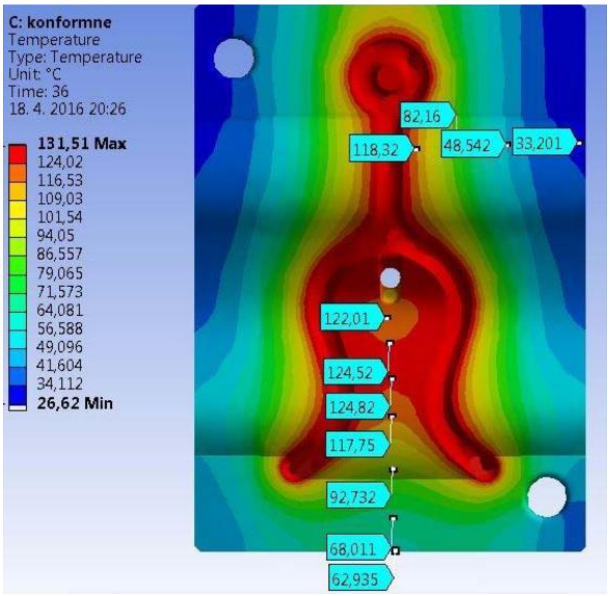

Figure 7: **View of temperature distribution for conformal cooling – view 1**

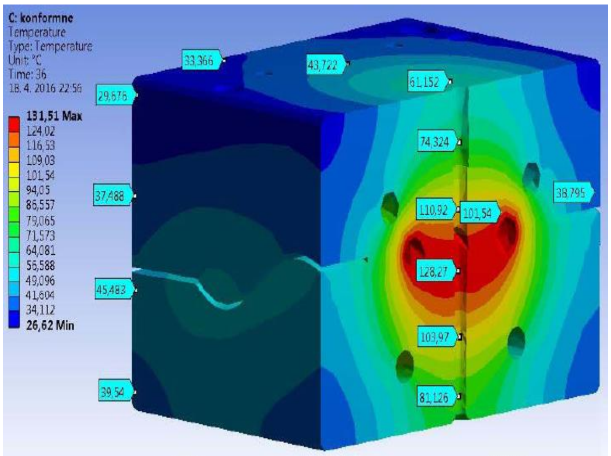

Figure 8. View of temperature distribution for conformal cooling – cut 1

Fig. 8 shows comparison of simulation with conventional cooling and is monitored changes in temperature range, what mean, that mold surface is cooler and temperatures on the surface are mostly up to 50°C. Some places are near to simulate temperature of the environment 25°C. Temperature in the place of the cut is in average about 5°C lower than at conventional cooling.

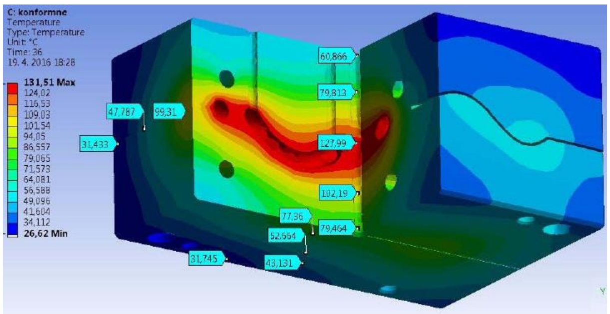

Figure 9. View of temperature distribution for conformal cooling – cut 2

In comparison with simulation of conventional cooling is average decrease in mentioned areas on the surface around 4,5 °C (Fig. 9). Probes situated vertically to the cut of the form are in the range from 60,87°C to 127,99 °C. In this area the temperature was reduced by approximately 4 °C.

3.3 *Combined cooling*

At the edges of the mold especially on upper part, where is situated conformal cooling are values of temperature are almost the same as values obtained by simulation (Fig. 10).

Cuts of the mold based on temperature ranges can be stated, that heat transfer on surface of the mold was decreasing in comparison with conventional way of approach (Fig. 5) and conformal cooling (Fig. 8), and more significant differences were monitored in comparison with conventional cooling.

Base on average temperature measured by situated probes in the cut can be stated, that at conventional cooling was temperature decreased about 9°C and about 4°C at comfort cooling.

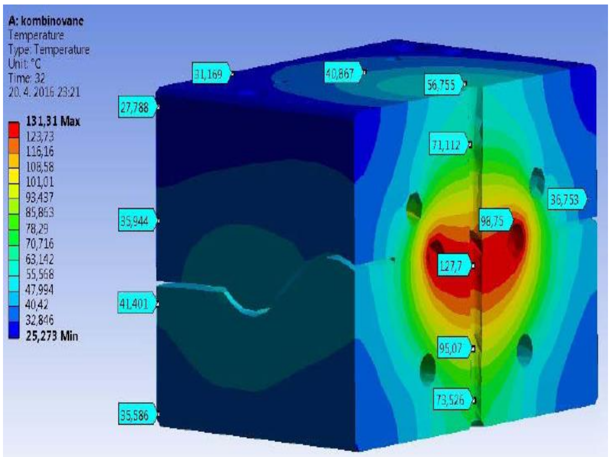

Figure 10. View of temperature distribution for combined cooling – cut 1

View on fig. 11 describe differences on mold surface in temperature ranges in comparison with conventional cooling (Fig. 7) and conformal cooling (Fig. 10), where significant changes are monitored by vertical probes situated in vertical ax in the center of mold section.

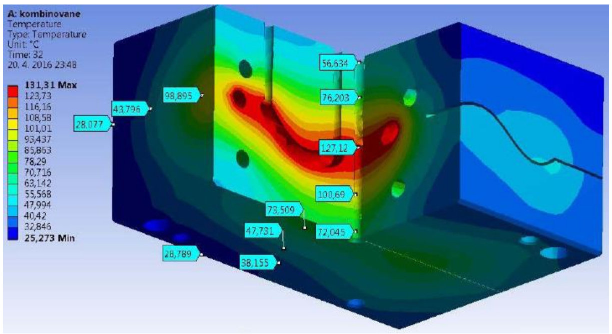

Figure 11. View of temperature distribution for combined cooling – cut 1

4 CONCLUSIONS

Results of the experiments are in terms of cooling and heat transfer the best at combined cooling for valid hypothesis, that both cooling cycles are active.

Differences between conventional and conformal cooling were confirmed, but more significant differences were monitored in experiment comparing conventional and combined cooling. Using conformal cooling provide information about difference, but in mention case is place for optimization of the conformal cooling, because its maximal potential wan not obtained from the reason of situation of the conformal cooling at the top of the mold form.

Can be expected, that optimization of the conformal cooling also in the bottom of mold could affect the heat transfer, what directly influence manufacturing time.

Important parameter is the fact, that introduction of the conformal cooling significantly decrease time of injection and also is obtained homogeny heat transfer, what afford to decrease of production time and decrease heat transfer from mold form and final product is on higher quality.

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