Conformal cooling with heat-conducting inserts by direct metal laser sintering

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Abstract. With the development of layer manufacturing technologies injection mold inserts with conformal cooling channels can be manufactured. If the cooling channels can be placed along the geometry, the heat removal is uniform and effective. In tight mold regions, formation of cooling channel is not possible or not efficient. The combination of conformal cooling and heat conductive insert can be an ideal solution for the effective cooling.

1. Introduction

Injection molding is one of the most important polymer processing technologies. The cooling time of the part is a significant phase of the injection molding cycle, which can amount to more than half the whole cycle. One of the best ways to achieve a reduction in cooling time is to use mold inserts with conformal cooling. The conformal cooling channels follows the geometry of the product, which cannot be manufactured with conventional methods, such as drilling or milling. As a result, it can extract more heat and the temperature distribution is more uniform. With additive manufacturing technologies, parts with complex internal structures can be built, which can be a major advantages for injection molds. The cooling channels can have complex form, which cannot be manufactured with conventional methods, such as drilling or milling. Injection mold inserts with conformal cooling can be manufactured by additive manufacturing [1].

Selective Laser Sintering (SLS) is an additive manufacturing process that allows the building of complex parts through the solidification of multiple layers of powders. A high power laser provides the thermal energy required for the powder sintering. The metal based SLS process is called Direct Metal Laser Sintering (DMLS) [2].

In case of injection molds from steal alloys, the tool with conformal cooling channels can extract more heat than with conventional cooling, but in many cases a tool from good thermal conductive copper based alloy can extract more heat with conventional cooling compared to steel tool with conformal cooling [3].

In some cases, formation of conformal cooling channel is not possible for geometric reason, mainly in tight mold regions. These hot spots have high impact on the part quality and cycle time. Tool steels have low heat conductive capacity compared to poor aluminium, copper or silver [4]. The combination of conformal cooling channels and fitted heat conductive inserts can serve an ideal cooling solution for tools with tight mold regions [5].
In our research work an injection moulding tool insert with conformal cooling channels was designed by modifying that of having conventional cooling system (finger). As reference the model of the original tool was used (Figure 1.) and to compare the efficiency of cooling, thermal simulations were carried out. Fitting of the new tool insert to the existing cooling circuit and the linear design of the cooling channels were important aspects of the design. The original tool insert was made of 1.2343 steel.

![3D model of the original insert.](image)

**Figure 1.** 3D model of the original insert.

2. **Design and simulation**

2.1. *Conventional tool insert (original)*

For the injection molding simulations Autodesk Moldflow (2014) software was used. The parameters used for the simulation derived from the production. The results of the simulation in the case of original tool were checked by thermal imaging. The thermographic image of heat distribution confirmed the accuracy of the simulation model. Based on the results of both simulation and thermographic test in terms of cooling the protruding surfaces were identified as the critical areas of the original tool (Figure 2.).

![The 3D model and the temperature distribution of the original mold.](image)

**Figure 2.** The 3D model and the temperature distribution of the original mold.

2.2. *Tool insert with conformal cooling*

Using the original model, a version with conformal cooling was designed, fitted to the previous system with Ø4 mm holes. As the minimum allowable distance between the cooling circuit and tool wall, 3 mm was determined. Direct cooling of the protrusions was discarded, even using small (Ø1.5 mm) cooling hole can serve only a partial solution, but this application can cause the clogging of the thin
channel. The own designed mold with the conformal cooling channels and the result of the thermal simulation can be seen on (Figure 3.).

![Figure 3. The mold with conformal cooling and the temperature distribution.](image)

Comparing the simulation results of the original and conformal cooling systems it can be concluded, that by following the same initial conditions better cooling efficiency cannot be achieved by conformal cooling.

2.3. Hybrid tooling
Since we could not achieve positive result with the conformal cooling itself, a special solution was designed. By using a good thermally conductive material the heat from the critical areas was lead to the cold parts. Thermal conductivity of tool steels and other metals with high coefficient can be seen in Table 1.

| Material                      | Thermal conductivity at 20 °C (W/mK) |
|-------------------------------|--------------------------------------|
| MaragingSteel MS1 (age hardened) | 20                                   |
| 1.2343                        | 25.3                                 |
| Copper                        | 398                                  |
| Silver                        | 418                                  |

Table 1. Thermal conductivity of mold steels and high conducting materials [6][7][8].

Based on the temperature distribution image of the tool insert the formation of conformal cooling is not necessary along the full length of the insert and therefore the tool was divided into a conventional produced part and a built part. From those parts, which cannot cool by the cooling channels, the heat was removed by thermocouples. For this purpose two pieces of Ø2 mm pin and a 2 mm thick sheet were used (Figure 4.). In terms of thermal conductivity, pure copper or silver inserts are the most efficient. The application of pure silver was rejected, because of its softness and thus the low strength the tight fitting of inserts is difficult to implement.
Figure 4. Copper inserts (a) and the computed tomography image of the built tool with the inserts (b).

Thermal distribution of the tool containing copper inserts is shown in Figure 5. It is important to note that in the simulation there was no air gap between the inserts and the mold. To achieve the simulation results in practice a production process solution is needed to apply in that the copper inserts are continuously connected to the wall of the tool and contact with the coolant.

Figure 5. The mold with conformal cooling and the temperature distribution.

The cooling efficiency of the mold with the copper inserts was examined during the complete injection molding process. It can be seen in Figure 6 that by the end of the cooling time (19 s) ~9 °C lower temperature of the critical section could have been achieved with the new design than that of the original cooling system in the same section. Moreover, due to the conformal cooling the temperature distribution of the mold became much smoother.
3. Manufacturing of hybrid tool

The production of the tool insert with the new design was carried out by Direct Metal Laser Sintering, which is a multi-step process. As a first step, the tool is printed with the insert height and then stopped the process (Figure 7a). Then metal powder is removed from the hole and the insert is placed into that (Figure 7b). It is important that the top of the insert must be in the same plane with the last layer of the built part (Figure 7c) and then continue to build (Figure 7 d). To ensure the best filling with the insert, after reversing the tool it can be melted in the hole with a brazing process (Figure 7 e).

![Figure 7](image)

**Figure 7**. Manufacturing process of hybrid tool (a-d) and a computed tomography image in one section (e).

The connection of the tool and the copper insert were examined by computed tomography and cross sectional optical microscopic images. After the powder deposition the upper part of the copper
insert is scanned by laser beam, so interesting to observe the interface of the two materials. In our experiments EOS M270 DMLS equipment was used with parameters applied for MS1 type maraging steel sintering. No porosity was detected in the region of steel-copper connection (interface area) by CT investigation (Figure 8.) and the same results were found by optical microscopic observation in the cross section (Figure 9.). Despite the tight fit air gap remained between the copper insert and the wall of the tool without heat treatment (Figure 8.).

By heat treatment above the melting point of the copper of the inverted parts the coherent surface air gap decreased. Based on the cross sectional optical micrographs it can be stated that there is a good wetting between the copper and the MS1 sintering steel. The molten copper is filling in the pieces of the surface roughness and micro-cavities formed in a continuous connection between the two metals (Figure 9.)

4. Conclusions
Direct metal laser sintering has growing interest in tool manufacturing due to its several advantages over conventional technologies. One of the main application filed of this technology is polymer injection molding. Providing even cooling is a challenge for certain products. Design and manufacturing of tool inserts with conformal cooling channels seems to be an effective solution for this problem.

In our paper a tool insert having conventional cooling system (finger) was redesigned with conformal cooling channels and thermal simulations were carried out. Based on the test results in terms of cooling the protruding surfaces were identified as the critical areas of the original tool.
Because of using conformal cooling system could not be achieved better cooling efficiency, a special solution was designed. Copper inserts were used to lead the heat from the critical areas. A hybrid tool insert were designed composed of a conventionally produced part and a built part with conformal cooling channels and copper inserts. The cooling efficiency of the mold was better, by the end of the cooling time lower temperature of the critical section and much smoother temperature distribution could have been achieved.

In the other part of our research work hybrid tool with the copper inserts were produced by DMLS and the connection of the tool and the insert were examined by computed tomography and optical microscopy. The cross sectional micrographs showed good wetting between the copper and the MS1 sintering steel.

Based on the experiments the new design of cooling system with combination of conformal cooling and heat-conducting pins and by combination of conventional manufacturing and additive technology seems to be an effective and recoverable investment.

Acknowledgments
The authors would like to thank to EFOP-3.6.1-16-2016-00017 ‘Internationalisation, initiatives to establish a new source of researchers and graduates, and development of knowledge and technological transfer as instruments of intelligent specialisations at Széchenyi István University’ for the support of the research.

References
[1] Zink B and Kovács J G 2017 The effect of limescale on heat transfer in injection molding Heat and Mass Transfer 86 101-107
[2] Lee H, Lim C H J, Low M J, Tham N, Murukesham V M, Kim Y-J 2017 Lasers in additive manufacturing: A review International Journal of Precision Engineering and Manufacturing-green Technology 4/3 307-322
[3] Zink B, Szabó F, Hatos I, Suplicz A, Kovács N K, Hargitai H, Tábi T, Kovács J G 2017 Enhanced injection molding simulation of advanced injection molds Polymers 9(2) 77
[4] Westhoff R 2006 Thermal balance: conformal cooling on the advance Kunststoffe International 8 24-26
[5] Merklein M, Junker D, Schaub A, Neubauer F 2016 Hybrid additive manufacturing technologies – an analysis regarding potentials and applications Physics Procedia 83 549-559
[6] Material data sheet: EOS MaragingSteel MS1, http://www.eos.info/ (28 May 2018)
[7] Dörrenberg: 1.2343, http://www.doerrenberg.de/ (28 May 2016)
[8] http://www.morganbrazealloys.com/downloads-3/mechanical-physical-properties (28 May 2016)