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CAE ANALYSIS OF CONFORMAL COOLING APPLICATION – CASE STUDY

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ABSTRACT: *Cooling system of injection molds is of high importance as it affects directly quality of molded parts and overall productivity of the process. Poor cooling system design leads to unnecessary long cycle times and also to quality issues of molded parts. State of art additive manufacturing technologies broadens the possibilities of cooling channel design and offer cycle time reductions as much as 60% in some cases. In this contribution, CAE cooling analysis is performed on existing mold that has issues with long cycle times and part quality due to improper cooling system design. The actual design is compared with new proposed design that features conformal cooling.*
KEYWORDS: *conformal cooling, CAE analysis, case study*

INTRODUCTION

Mold cooling system is very important in terms of product quality and overall process productivity. Improper design of cooling system leads to unnecessary long cycle times and poor quality of molded parts. Non-uniform shrinkage due to cooling rate variations within the mold often leads to warpage, sink marks and other quality issues. The only way how to deal with warpage is to run longer cycle times and use the mold as a fixture. With longer cycle times often with the higher mold temperatures, heat transfer rate is decreased and so its gradients thus the molded part temperature can fully equilibrate across the mold. [1]

There are various objectives in cooling system design, maximum heat transfer rate and uniform wall temperature are the most important. Heat transfer rate is proportional to thermal conductivity of the mold and to temperature gradient. Therefore to increase the heat transfer rate one must use either higher thermal conductivity materials for mold inserts or position the cooling lines closer to the surface. Positioning of conventional gun drilled cooling channels is limited. State of art additive manufacturing methods enable more freedom in positioning of cooling channels. DMLS method is one of the most recognized methods for producing mold inserts with close contour cooling channels.. Mold inserts are produced from metal powder via laser sintering. Further operations include heat treatment and finish machining to final dimensions.

Toolmaking is generally a costly and time-consuming activity, involving many process steps, expensive equipment and qualified personnel. Using conventional manufacturing technologies, even a relatively simple two-part (open-shut) injection mould typically requires CNC milling combined with EDM to produce the molding geometry of the cavity and core. Deep slots or sharp internal corners require production of EDM electrodes by CNC machining. Complex tooling also often requires sliders, removable inserts or other features, which make the production even more complex and therefore costly and time-consuming. Therefore is often a high motivation to apply methods which can save time and costs in tooling production. DMLS can greatly contribute to this by replacing milling and EDM steps. [2]

Conformal cooling application due to higher costs for DMLS inserts also requires in-depth analysis for feasibility evaluation and return on investment confirmation. As was reported in [3], there was no CAE software capable of handling cooling analyses with complex 3D channels with different cross-sections back in 2009. However, today for example Moldex3D (by CoreTech System Co., Ltd.) features this functionality and also supports 3D surface cooling methods.

EXPERIMENTAL

The aim of this contribution is to validate the benefits of conformal cooling for reduction of cycle time in injection molding on a case study. The motivation for this contribution was an existing injection mold with very long cycles because of inappropriate cooling. It was two-cavity mold for molding pallet corner guards. The core of the mold for this part consists of 4 segments. The part along with the four core segments is shown in Figure 1. The actual cooling system of the mold is shown in Figure 2. Notice, that there is no cooling in the segment 3 of the core. Segment 4 is cooled by two copper rods that are cooled by water in the bottom. The result of this cooling system is that the mold is not capable to produce parts within acceptable cycle time and the parts are of poor quality since the ejector pins *located in segment 3 protrudes the part during ejection. In shorter cycle times the pins even penetrate the part in this location. To compare the existing cooling layout with conformal cooling, two conformal cooling designs were proposed. In the first case, the core remains divided into 4 segments as in original design, conformal channels are provided to segment 3 and 4 as shown in Figure 3. Segments 1 and 2 are cooled via baffles as in original design.*

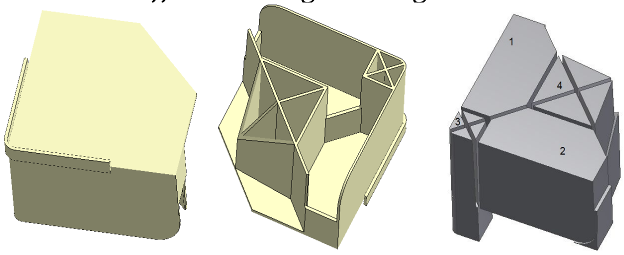

Figure 1. Mold cooling system layout, fixed half (left), movable half (right)

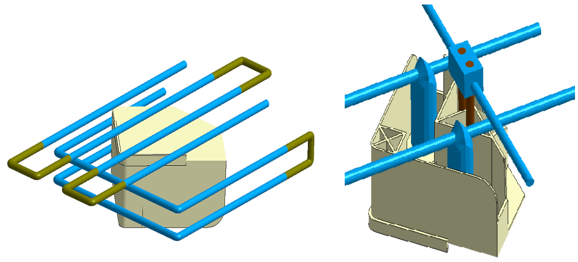

Figure 2. Mold cooling system layout, fixed half (left), movable half (right)

In second design, the core is one solid insert with 3 conformal channels as shown in Figure 4. For both conformal cooling designs the cavity cooling was adopted from original design. CAE analysis was run with original cooling system design and conformal cooling system designs according molding conditions shown in Table 1. To compare the mold temperatures same cooling times were set for all three cases. In addition the original design was analyzed in total three different cooling times to investigate the influence of cycle time on mold temperature distribution and to find the cycle time required for cooling the part to ejection temperature. Full 3D analysis was adopted for simulating this design to evaluate the mold temperature distribution. CAE models were meshed with 3d mesh including part, runner system, mold base and mold inserts. Generally, cycle average temperature is being used for cooling analysis in conventional injection molding, however, this approach is valid when there are no significant mold temperature differences. In this case the mold temperature differences were expected to be high since the cooling of the mold is evidently non-uniform. Therefore transient analysis was adopted for solving the mold temperature distribution through the cycle.

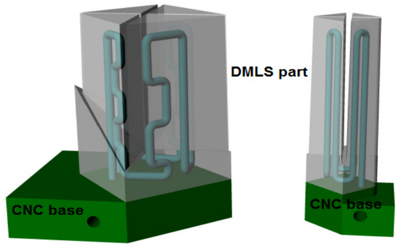

Figure 3. Conformal cooling design 1 - conformal channels in segment 3 and 4

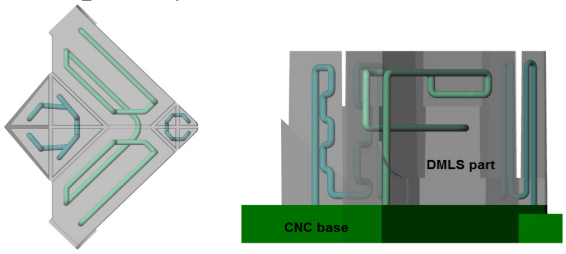

Figure 4. Conformal cooling design 2 – one solid core segment

Table 1. Process conditions used in analyses

Process	Melt T[°C]	Mold (coolant) T[°C]	Fill [s]	Pack [s]	Cool [s]	Mold open [s]	Ejection T [°C]	Cycle [s]
Original design	145	30 (25)	2	12	20	5	145	39
	145	30 (25)	2	12	40	5	145	59
	145	30 (25)	2	12	60	5	145	79
CCC 1	145	30 (25)	2	12	20	5	145	39
CCC 2	145	30 (25)	2	12	20	5	145	39

RESULTS

The actual mold temperature distributions at the end of the cooling time with cooling times of 20s, 40s and 60s are shown in Figure 6. Longer cycle times provided for heat dissipation from hot spots. At cooling time 20s the highest temperature of segment 3 at the end of cooling time was 197°C while at cooling time 60s, the hot spot was reduced to 150°C. This however is still above the ejection temperature of the part, thus the material in this location could not be cooled to ejection temperature even after cooling time of 60s. In Figure 7 we can see the comparison of predicted melting core

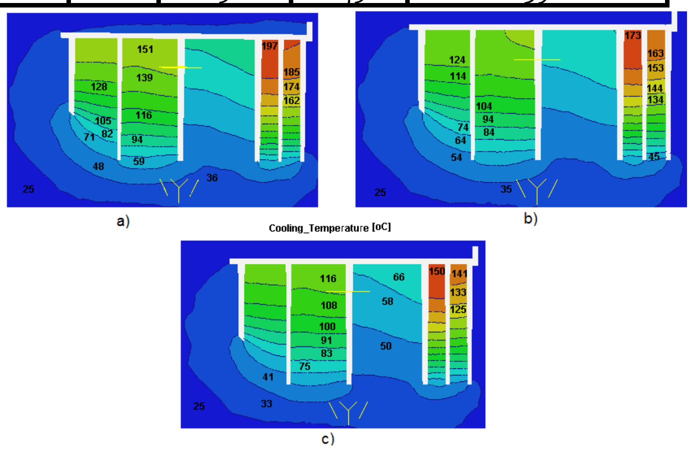

Figure 6. Mold temperature distribution at the end of cooling, a) cooling time 20s, b) cooling time 40s, c) cooling time 60s

after 20s of cooling time and after 40s of cooling time. Melting core after 60s was only very little area at the top rib cross of segment 3 where is high concentration of material.

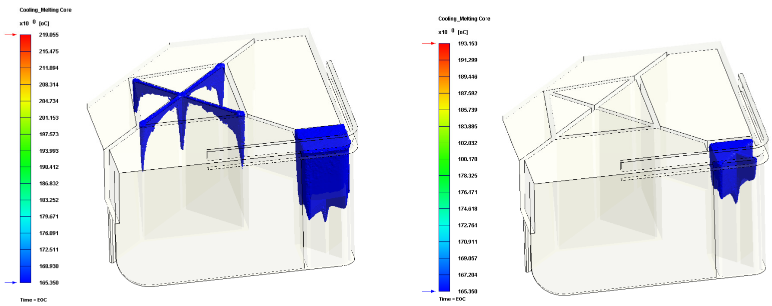

Figure 7. Melting core prediction, cooling time 20s (left), cooling time 40s (right)

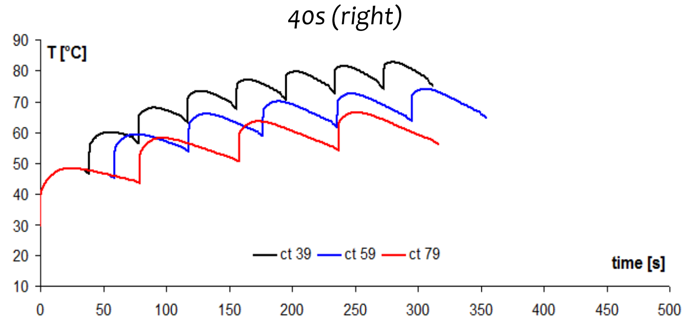

Figure 8. Average mold temperature history plots for different cycle times

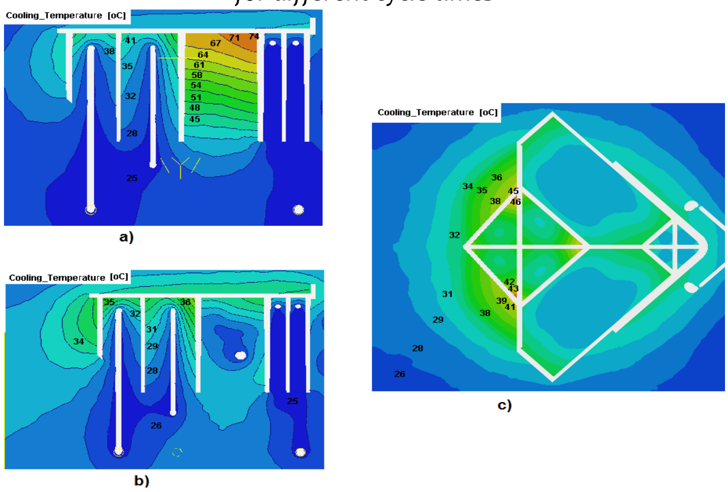

Figure 9. Mold temperature distribution at the end of cooling time 20s – conformal cooling, a) ccc1, b) ccc2 y slice, c) ccc2 z slice

The blue surfaces in this result encapsulate the material that is above the freeze temperature that is 165°C. The average mold temperature history plot for the different cycle times is shown in Figure 8. We can see from this result how average temperature of the mold decreases with longer cycle times, also less cycles are needed to get to a stable cycle with increasing cycle time. It took 8 cycles to get to the stable cycle in case of cooling time 20s (cycle time 39), only 4 cycles were needed in case of cooling time 60s (cycle time 79). The maximum cooling time predicted by analysis when the actual cooling time was set to 20s was 111s, and for cooling time set to 40s and 60s, it was more or less 34s for both cases. However we cannot set such low cooling time for this part because the temperature of the hot spots will raise if cycle time was reduced as was demonstrated at temperature history plots. Thus we can assume that minimum cooling time for this part to cool to ejection temperature would be 60s with overall cycle time of 79s.

The first design of conformal cooling provided as was expected much better results for mold temperature distribution and also for cooling time. In Figure 9 we can see the mold temperature distributions of both conformal cooling designs. In first design, the hot spots moved into top corners of segments 1 and 2 farthest from the cooling baffles. Maximum observed temperatures of hot spots at the end of cooling time was 74°C. In case of second conformal design, the hot spots were observed in top corners of core segment 4 with maximum temperatures at the end of cooling 46 °C. Melting core after 20s of cooling time for both conformal cooling designs is shown in Figure 10. Again the blue surfaces represent the material that is above the freeze temperature. At these conditions we can assume that the part could be ejected from the mold after 20s of cooling time. And we can assume that the overall cycle time of 39s could be used as input into breakeven analysis. Conformal channels were also able to achieve stable production cycle much faster than original design, the temperature history plot is shown in Figure 10 for both conformal designs.

Breakeven analysis was performed for first conformal design with separated core segments. Analysis was based on actual cost for the existing mold, machine hour rate, cost estimation for the inserts

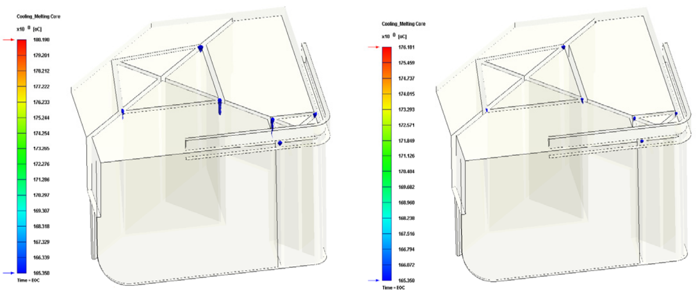

Figure 10. Melting core prediction after 20s of cooling time, ccc1 (left), ccc2 (right)

with conformal cooling and results from cooling simulations. The cost of the existing mold was 21 700 €, machine hour rate is 25 €, costs of total 2+2 DMLS mold inserts for two cavity mold was estimated to 4800 €. Production volume is about 25000 parts per year. The plot form breakeven analysis is shown in Figure 12. It is clear that the return on investment could be achieved after molding about 35000 parts.

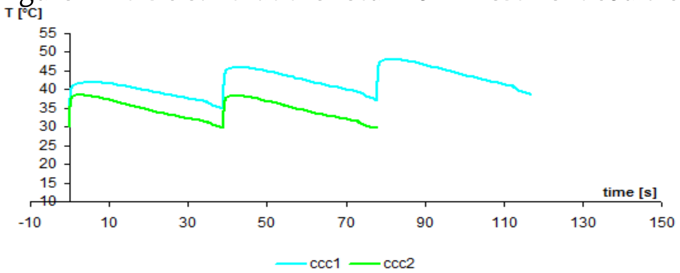

Figure 11. Average mold surface history plot - conformal cooling

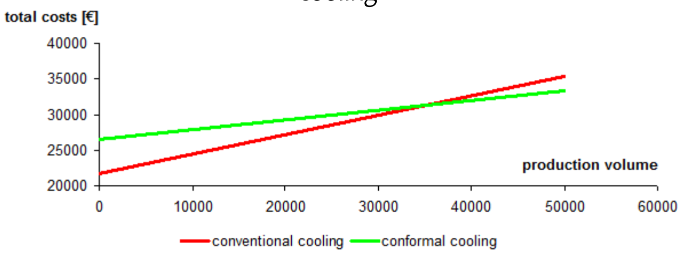

Figure 12. Breakeven analysis conventional cooling vs. conformal cooling

CONCLUSIONS

Although the cycle time reductions achieved were significant, the return on investment for mold inserts with conformal channels is more than a year. That is due to lower production volume. However conformal inserts could save 139 machine hours per year and the machine could be used for molding of other products.

The efficiency of conformal cooling was approved in this study. Many plastic parts today have similar features like the part in this study that is impossible to cool by conventional methods, therefore conformal cooling has potential for growing in applications. Also the software used in this study has strong credibility to handle analyses of conformal cooling and provides reasonable results for evaluation of conformal cooling applications.

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