View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Ghent University Academic Bibliography

Thermal behaviour of hybrid injection moulds for short production series

S. Boden, T. Wieme, M. Erkoç, L. Cardon

Centre for Polymer and Material Technologies CPMT, Department of Materials, Textiles and Chemical Engineering, Faculty of Engineering and Architecture, Ghent University (Belgium)

ABSTRACT: This study investigates if polymer based additive manufactured (AM) mould inserts can be used as hybrid injection moulds by analysing the thermal and mechanical behaviour of polymer hybrid mould inserts. First a proper additive manufacturing technique will be chosen comparing previous studies. Afterwards mould inserts will be designed and manufactured. Once the inserts are produced, thermal and mechanical material characteristics are determined. Before testing the inserts in experimental setup, CAE software is used to simulate the thermal and mechanical behaviour of the hybrid mould defining optimal injection moulding parameters. Finally the inserts are tested in a real injection moulding cycle.

Keywords : Injection moulding – Hybrid moulds – Thermal behaviour – Powder bed fusion

1 INTRODUCTION

Injection moulding is one of the most common used processes in the production of plastic parts. The process is mainly used in mass production processes where the same part is being created thousand, even million times. The basic principle of injection moulding is based on melting a solid polymer so it can be injected into the cavity of a mould. After injecting the polymer, the part cools down and it can be ejected from the mould. The cost-efficiency of this process is determined by the time spent in this cycle. Considering that the cooling phase request the biggest time, it is obviously that this phase determines the rate at which the parts are produced. The longer the time to produce parts, the more the costs (Dimla, Camilotto, & Miani, 2005). Therefore moulds are mostly made in highly thermal conductive materials with high strength and wear resistance such as conventional mould steel.

For the production of small series it is possible to use a low-cost mould to reduce the cost per unit. Those moulds can be developed by use of cheaper production methods or an alternative material selection. One of the options is to use additive manufacturing for the production of mould inserts. The time to produce these mould inserts is very low, which would be ideal for designing prototyping moulds.

2 STATE OF THE ART

Hybrid mould inserts are made by use of an additive manufacturing process, followed by some conventional tooling to achieve optimal surface structure, tolerances, etc (Attanasio et al., 2006). This study is about selecting and testing a suitable additive manufacturing process for short production series. The material and production costs will reduce by selecting an AM process that manufactures plastic moulds, since plastics are far cheaper to grind and process than metals. On the other hand the AM mould inserts need to fit the injection moulding characteristics.

(Attanasio et al., 2006) investigates the use of stereolithography (SL - VAT photopolymerization based AM) to produce mould inserts. In this study they tested the influence of different cavity and core combinations: steel cavity with SL core, SL cavity with steel core, SL insert with epoxy resin backfilling… As a result they concluded: “To obtain a proper internal flow the temperature difference between both mould halves can’t be too big. In other words the thermal conduction and behaviour from both mould inserts should be equal.” (Gobbin, 2017) made her master dissertation about hybrid moulds. She tried several additive manufacturing technologies to create hybrid moulds. A low-cost stereolithography method produced inaccurate parts, which needed a lot of post-processing before actually using them.

(G. Kovacs et al., 2015) investigated the direct rapid tooling techniques of material extrusion to create mould inserts. Using a standard polymer filament as primary material, the mould temperature was very difficult to control. Due to the porosity and inability to produce parts, the polymer extrusion based mould insert cannot be used for injection moulding. By use of special designed filaments, it resulted in better parts but still after some injection cycles the delamination effect causes the mould inserts to be useless.

(G. Kovacs et al., 2015) also investigates the use of a material jetted mould insert. They stated that material jetting has remarkable advantages over material extrusion technology for hybrid mould applications. The main advantages are the surface finish, density and heat removal capabilities of the model. However the unequal distribution of temperature at the surface needs to be taken into account.

Finally (Gobbin, 2017) also used the Fusion Jetting Technology (FJT) to create sintered mould inserts. FJT can be used as a proper technique to produce direct soft tool inserts for injection moulding. However there are some post-processing operations needed. The manufacturing technique is rather accurate. Reaming ejector holes to the desired tolerance was needed. Before injecting any material, the inserts need some surface coating to avoid adhesion of injected polymer onto the mould insert. This coating acts as filler for the porous structure of the FJT technique. Without those fillers the injected material will stick onto the inserts, causing ejection problems.

3 MATERIALS AND METHODS

The research discussed in this paper uses a special designed mould base for small inserts, with external ejection unit, as illustrated in Figure 1.

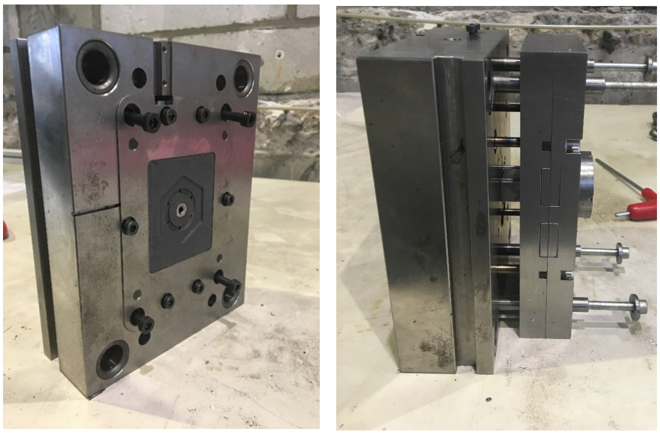


Figure 1: Mould base for AM inserts

The cavity is designed to shape a spinning top demo part. The drawing of the cavity insert is illustrated in Figure 2.

The inserts are manufactured with the HP Fusion Jetting Technology. The inserts are made in Polyamide 12. To compare the AM technologies, a second set of inserts is produced by use of the Binder Jetting Technology BJT (ZPrinter).

The injected polymer is Sabic PP 575L. To guarantee proper injection moulding parameters during experimental testing, simulations are executed using Moldex3D. To investigate the simulation, previously the material properties of the AM produced inserts are analysed.

Finally when suitable parameters are retrieved, experiments are performed on an Engel E-Victory 28T injection moulding machine with screw diameter 22 mm.

To compare the thermal results retrieved from the injection simulation and experimental data, infrared analyses are made with a Testo 875 IR Camera. The mould inserts and moulded products are dimensionally analysed with a Keyence VHX-500F microscope.

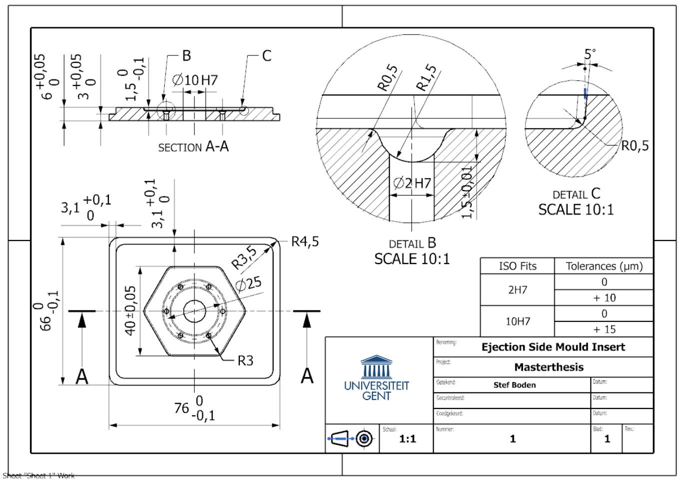


Figure 2 : Design cavity side mould insert

4 MOULD INSERT MATERIAL PROPERTIES

Table 1 gives a comprehensive overview of experimental retrieved data for thermal and mechanical behaviour of the AM mould inserts.

Table 1. Material properties different inserts.

Parameter	FJT*	BJT*
Conductivity [W/mK]	0.3161	0.3477
Heat capacity [J/kgK]	1470.7	1171.9
Density [g/cm³]	1.029	1.778
Young's modulus [GPa] **	1.359	/
Yield stress [MPa] **	15.35	/
Tensile strength [MPa] **	42.09	/

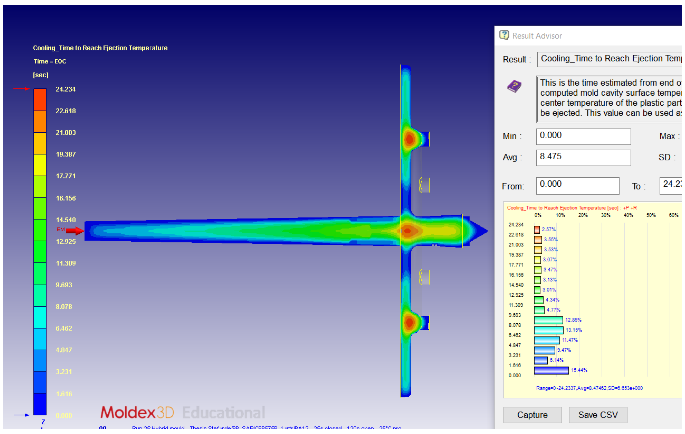
* FJT = Fusion Jetting, BJT = Binder Jetting

** Tensile test dog bones only retrieved for FJT inserts

5 THERMAL SIMULATIONS

5.1 *Cooling time*

By use of Moldex3D the heat exchange during injection moulding cycle is calculated. Via steady state analysis, the ejection temperature – cfr. mould opening time - of the moulded product is retrieved. This cooling time, illustrated in Figure 3, increases due to low thermal conductivity of the polymer inserts. At the metal sprue gate and other metal inserts such as ejector pins, the cooling time is significantly reduced.



Result : Cooling_Time to Reach Ejection Temp

This is the time estimated from end o
computed mold cavity surface tempe
center temperature of the plastic part
be ejected. This value can be used a

Min : 0.000

Max :

Avg : 8.475

SD :

From: 0.000

To : 24.2

Figure 3 : Time to reach ejection temperature (cooling time)

Once the mould opening time is defined, a proper open-mould time needs to be determined before a new injection cycle can start. By transient solution analysis, it is possible to obtain the mould temperature at the end of the injection cycle. Figure 4 illustrates the inner mould temperature at the end of a d-selected cycle time. It can be noticed that the temperature inside the mould insert increases towards the cavity. After simulating of different open times, the optimal temperature distribution is selected at which the inserts are cooled down below the heat deflection temperature of the PA12 inserts.

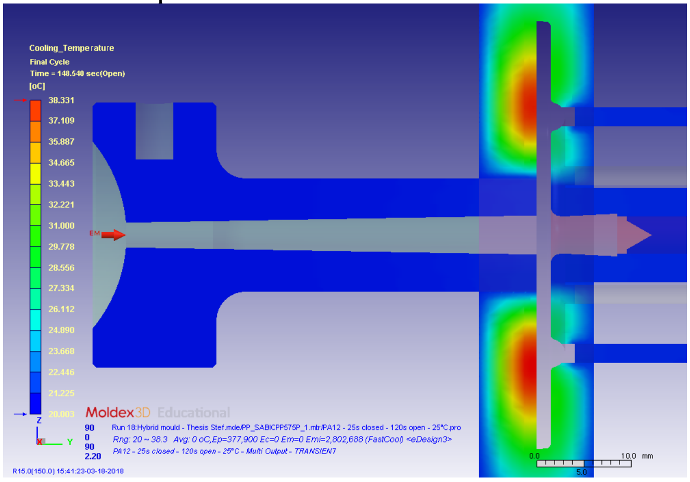


Figure 4: Temperature mould at and of cycle

Table 2 gives the comprehensive overview of the simulated injection parameters.

Table 2. Simulated injection parameters.

Parameter	FJT*	BJT*
Cooling time [s]	25	25
Open time [s]	90	90
Max. ejection temperature [°C]	104.05	98.26
Max . insert temperature [°C]	95.48	90.39
Insert temperature at end of cycle [°C]	32.45	33.80

* FJT = Fusion Jetting, BJT = binder jetting

5.2 *Theoretical injection parameters*

To ensure the AM mould inserts do not become damaged due to injection forces, the injection parameters must be optimized. Moldex3D is capable to simulate the influence of injection speed and holding time. These parameters also influence the thermal behaviour of the mould inserts.

A reduced injection speed (increased injection time) is needed to ensure the mould surface does not heat up due to a high shear rate. By reducing the injection speed, the injection pressure also reduces. The injection and holding pressure should always be below the yield strength of the mould insert material. Finally, the holding time is simulated by use of Moldex3D. Table 3 summarizes the injection moulding parameters after simulation.

Table 3. Theoretical injection parameters.

Parameter	Value
Injection time [s]	$0.5 < t < 2.0$
Clamping force [ton]	$1.55 < F < 4.31$
Injection pressure [bar]	$110 < p_1 < 155$
Holding pressure [bar]	$p_2 < 155$
Holding time [s]	3.0

6 EXPERIMENTAL RESULTS

6.1 *Number of injections*

The simulations predicted that BJT inserts would offer good results. Despite this, it was only possible to inject 13 parts. One insert even broken after moulding one part. On the other hand, FJT inserts offered very good results. It was possible to produce 133 moulded products with minor damage of the FJT inserts.

6.2 *Thermal behaviour*

Figure 5 shows the experimental IR-scan from the FJT PA12 insert after ejection, as Figure 6 illustrates the Moldex3D simulation result. Comparing the average temperatures, both experimental IR-scans and simulated results are equal.

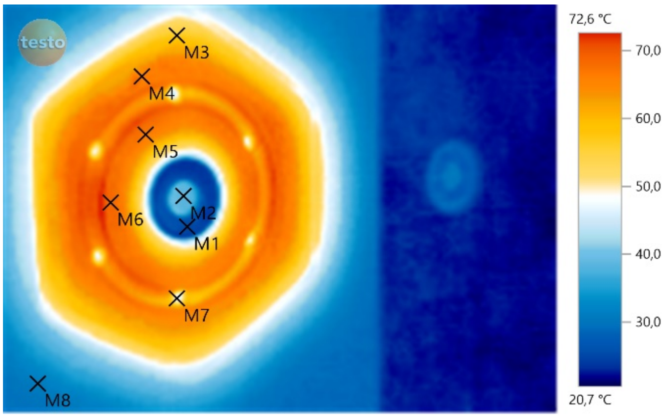


Figure 5: IR-scan experimental - cavity temperature after ejection

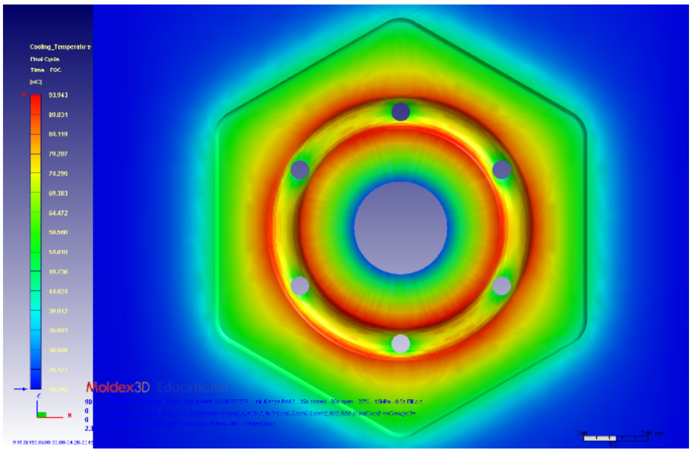


Figure 6: Moldex3D simulation – Cavity temperature after ejection

6.3 *Trapped air*

Figure 7 illustrates that the first few samples contain a lot of trapped air at the bottom part of the samples, due to low venting behaviour. The amount of trapped air is reduced significantly by executing more injection cycles. After 20 injection cycles no trapped air is noticed.

Figure 7: Trapped air inside produced part

By analysing the moulded parts with a Keyence VHX-500F microscope it is possible to measure the ejection shaft diameter at the location of trapped air.

The average ejection shaft diameters are plotted in the diagram of Figure 8. The average diameter increases from 2220 µm to approximately 2270 µm. During experimental work, the trapped air disappears as from sample 20. The diagram shows that the average shaft diagram is increased with 50 µm after 20 injections. This 50 µm allows the trapped air to be removed properly.

The reason for these phenomena is that the metal ejector pins heat up and expand in short time. On the other hand, the FJT PA12 inserts will heat up slowly, resulting in a decrease of the predefined venting clearance between ejector and drilled hole. After 20 cycles, the ejector pins erode a minor amount of FJT PA12 insert.

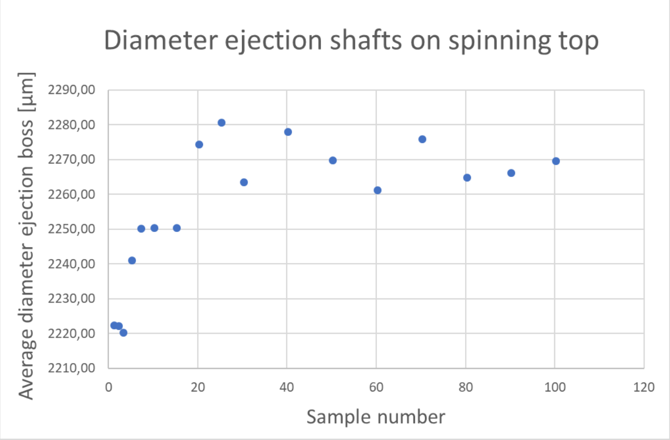


Figure 8: Average diameter ejection shaft on moulded product

7 CONCLUSIONS

The purpose of this study was to investigate if it is possible to use polymer based FJT and BJT inserts for injection moulding by analysing the thermal and mechanical behaviour. Despites the rather bad results from the BJT inserts due to its limited mechanical behaviour, FJT inserts offer good results. Table 4 and 5 illustrate the overview of both theoretical and experimental results for FJT inserts.

Table 4. Theoretical and experimental injection parameters

Parameter	Theoretical	Experimental
Cooling time [s]	25	25
Mould open time [s]	90	90
Injection time [s]	$0.5 < t < 2.0$	$t < 0.5$
Clamping force [ton]	$1.55 < F < 4.31$	2
Injection pressure [bar]	$110 < p_1 < 155$	165
Holding pressure [bar]	$p_2 < 155$	30
Holding time [s]	3.0	5.0

Table 5. Theoretical and experimental thermal behaviour

Parameter	Theoretical	Experimental
Cavity		
Temperature after ejection [°C]	$70 < T < 80$	$70 < T < 75$
Temperature end of cycle [°C]	$27 < T < 30$	$32 < T < 35$
Core		
Temperature after ejection [°C]	$75 < T < 85$	$65 < T < 75$
Temperature end of cycle [°C]	$27 < T < 31$	$32 < T < 35$
Moulded part		
Temperature after ejection [°C]	$75 < T < 85$	$90 < T < 100$

Despites these good results, further investigation are needed to optimize the injection moulding process and mould design. First if all, the open-mould cooling time can be optimized by use of forced convection. Secondly, it was noticed that the difference in mould material inserts and ejector pins influence the dimensional stability of the mould inserts, resulting in bad venting. In this case, a larger ejection hole diameter for better venting could be suggested. Finally, a more adequate heat resistant surface coating must be optimized to decrease insert porosity.

8 REFERENCES

Attanasio, D., Hopkinson, N., Kehrberger, R., Sridhar, A., & Witt, G. (2006). Application and modelling of hybrid stereolithography injection mould tooling, 23. https://doi.org/10.1080/17452750600924614

Dimla, D. E., Camilotto, M., & Miani, F. (2005). Design and optimisation of conformal cooling channels in injection moulding tools. *Journal of Materials Processing Technology*, *164–165*, 1294–1300. https://doi.org/10.1016/j.jmatprotec.2005.02.162

G. Kovacs, J., Szabo, F., K. Kovacs, N., Suplicz, A., Zink, B., Tabi, T., & Hargitai, H. (2015). Thermal simulations and measurements for rapid tool inserts in injection molding applications. *Applied Thermal Engineering*, *85*, 44–51.

Gobbin, A. (2017). *Vervaardigen van hybride spuitgietmatrijzen voor beperkte productiereeksen*. Ghent University.