



HAL
open science

Thermal transfer in laminated injection moulds and comparison of the mould assembly techniques

Eliette Mathey, Luc Penazzi, Fabrice Schmidt, François Ronde Oustau

► To cite this version:

Eliette Mathey, Luc Penazzi, Fabrice Schmidt, François Ronde Oustau. Thermal transfer in laminated injection moulds and comparison of the mould assembly techniques. ESAFORM 2003 -6th ESAFORM conference on material forming, Apr 2003, Salerno, Italy. p.63-66. hal-01788433

HAL Id: hal-01788433

<https://hal.science/hal-01788433>

Submitted on 5 Mar 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Thermal transfer in laminated injection moulds and comparison of the mould assembly techniques

E. Mathey, L. Penazzi, F. Schmidt, F. Ronde-Oustau

CROMeP (Research Center on Tools, Materials and Processes) – Ecole des Mines d’Albi

URL: www.enstimac.fr/recherche/mat/

e-mail: mathey@enstimac.fr

ABSTRACT: Recent studies have shown the possibilities to apply rapid prototyping methods for tool making. An advantage of these processes is the ability to obtain complex shapes (that would be impossible to obtain using machining). This aspect is particularly interesting to create cooling circuit in injection moulds. In this paper, conception of cooling circuit in laminated moulds is considered. After a description of steady state and transient heat transfer models in an injection mould, the influence of the cooling circuit geometry, the mould making technique (massive machined mould or laminated mould) and the bonding technique for laminated moulds (glued or brazed) is studied. Results show the advantage of a thermal barrier (which could easily be obtained in laminated tools) on mould thermal regulation. Discontinuities of mould material introduced by the lamination lead to a loss of thermal performance of the mould. However, a brazed mould shows performance almost equal to massive moulds.

Key words: laminate tooling, polymer injection, mould cooling, numerical simulation.

1 INTRODUCTION

Rapid prototyping processes are now applied to the tool making process to reduce development time, fabrication costs and delays. Among them, the StratoconceptionTM process consists in building pieces by assembling previously machined sheet laminates. In the case of steel, sheets can be assembled by glue or brazing [1]. This procedure has been successfully applied to the fabrication of the tools of several processes such as injection, SPF, RTM...[1,2,3] In the case of injection moulds, this process allows free and complex forms, especially for cooling channels following the piece surface [3]. Conception methods used today for the cooling or heating of injection moulds [4,5] need to be adapted to this new material and its behaviour.

The objectives of the present paper are, using numerical simulations on a disc-shaped mould, to show :

- the advantage of changing the cooling circuit geometry,
- the influence of the mould making process

(massive mould machining or lamination),

- the influence of the bonding technique (glue or brazing) on the heat transfer within a simple disc-shaped mould.

2 INFLUENCE OF THE MOULD GEOMETRY

2.1 Constitutive equations

Steady state computation in the mould is used to compare the mould capacity to evacuate heat provided by the polymer to the cooling fluid.

Steady state heat transfer in the mould yields equation (1).

$$\forall M \in \Omega_M \quad \nabla^2 T = 0 \quad (1)$$

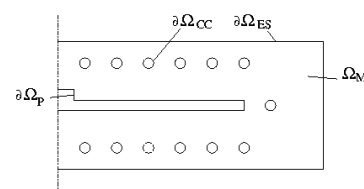


Fig. 1. Massive mould geometry and domain definition

The boundary conditions associated with the problem are (see fig. 1):

- A heat flux density representing heat provided by the polymer piece during the injection cycle is imposed on the mould cavity surface according to equation (2).

$$\forall M \in \partial\Omega_P \quad -\lambda_M \vec{\nabla}T \cdot \vec{n} = \Phi \quad (2)$$

where λ_M is the mould material thermal conductivity.

Heat provided by the polymer is due to cooling and crystallization according to equations (3) and (4) where ρ_P is the polymer density, V_P is the polymer volume, C_P is the polymer specific heat, ΔT is the difference between the polymer injection temperature and the mean ejection temperature, χ is the crystalline rate and H the massive latent heat of crystallization.

$$Q_{cooling} = \rho_P V_P C_P \Delta T \quad (3)$$

$$Q_{crystal} = \rho_P \chi V_P H \quad (4)$$

As the objective is to compare mould geometries, only a rough estimation of the heat flux is necessary and therefore, heat provided by crystallization is neglected. The heat flux density Φ is supposed to be uniform on the mould cavity surface and is then estimated by dividing heat provided $Q_{cooling}$ by the mould cavity surface A and the estimated cooling time t [4].

- A heat convection conditions is imposed on the cooling channel boundary (5). h is the convective heat transfer coefficient and T_∞ is the fluid temperature.

$$\forall M \in \partial\Omega_{CC} \quad -\lambda_M \vec{\nabla}T \cdot \vec{n} = h(T - T_\infty) \quad (5)$$

h is estimated from fluid flow properties :

$$h = \frac{Nu \lambda_F}{D} \quad (6)$$

where D is the channel diameter, λ_F is the fluid conductivity and Nu is the Nusselt number.

The flow rate is chosen to get a turbulent flow ($Re > 2300$). In this case, Nu can be estimated using equations (7) and (8).

$$Nu = 0.023 Re^{0.8} Pr^{1/3} \quad (7)$$

$$\text{with } Re = \frac{4\rho_F Q}{\pi\mu D} \text{ and } Pr = \frac{C_F \mu}{\lambda_F} \quad (8)$$

where Re is the Reynolds number, Pr is the Prandtl number, Q is the fluid flow rate, C_F is the fluid specific heat, ρ_F is the fluid density, μ is the fluid viscosity and λ_F is the fluid thermal conductivity.

- The outer surface of the mould is isolated as heat exchange with the ambient air and the press is neglected (less than 5% of the mould heat loss [8]).

$$\forall M \in \partial\Omega_{ES} \quad -\lambda_M \vec{\nabla}T \cdot \vec{n} = 0 \quad (9)$$

2.2 Numerical computation

Equation (1) is solved by a finite element method using ABAQUSTM. Different configurations of the cooling circuit are tested to evaluate the influence of the number, size and position of the channels. Injection of a polypropylene disc in a steel mould cooled with water is considered (Tables 1 and 2).

Table 1. Mould and polymer thermal properties

	Mould (Steel)	Polymer (PP)
λ (W.m ⁻¹ .K ⁻¹)	36.5	0.15
ρ (kg.m ⁻³)	7820	980
C (J.kg ⁻¹ .K ⁻¹)	460	1700

Table 2. Fluid properties and processing conditions

λ_F	0.6 W.m ⁻¹ .K ⁻¹	T_∞	20 °C
C_F	4.18 J.kg ⁻¹ .K ⁻¹	μ	10 ⁻² P
ρ_F	1000 kg.m ⁻³	ΔT	250-100=150 °C

2.3 Results

Temperature distribution is shown inside the mould in fig. 2 and on the mould cavity surface in fig. 3.

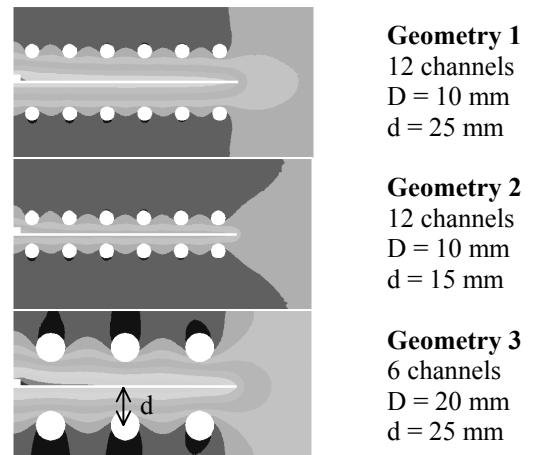


Fig. 2. Steady-state temperature distribution in the mould

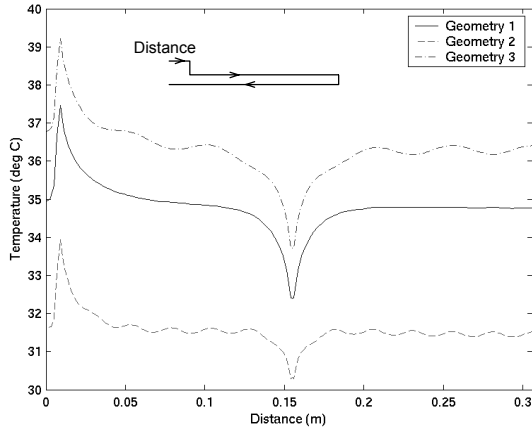


Fig. 3. Temperature distribution on the mould cavity surface according to cooling system geometry

Tendencies known by mould makers are similar to computations: a high number of cooling channels should be preferred to get a low homogenised temperature. Channels close to the mould cavity should be preferred for a low temperature but with a loss of the temperature homogeneity at the mould cavity surface. These results show the advantage of creating a cooling system surrounding the polymer piece.

3 EFFECT OF THE MOULD LAMINATION

3.1 Introduction of the lamination in the computation model

Stratification introduces discontinuities and material changes influencing the heat transfer in the mould. Among the different possibilities, it is taken here into account in the computation by introducing a thermal contact resistance on the interface between laminates.

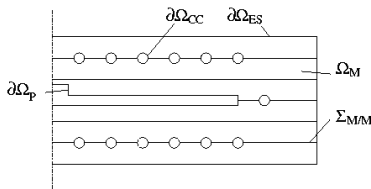


Fig. 4. Laminated mould geometry and domain definition

This resistance is evaluated by dividing the thickness e of the joint by its thermal conductivity λ .

Table 2. Interface properties according to assembly technique (RTG, Loctite, CEA)

	Glue	Brazing
e (mm)	0.3	0.03
λ ($\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$)	1.8	410
R_{MM} ($\text{m}^2\cdot\text{K}\cdot\text{W}^{-1}$)	$1.6 \cdot 10^{-4}$	$7.3 \cdot 10^{-8}$

3.2 Results

The effect of the stratification is different according to the bonding method (fig. 5 and 6). When brazing is used, no differences are found compared with the original mould. Thermal contact resistance is too low to influence the heat transfer between the mould cavity surface and the cooling channel.

When glue is used, the contact thermal resistance becomes high enough compared to the mould conductivity to influence heat transfer leading to a higher temperature on the mould cavity surface.

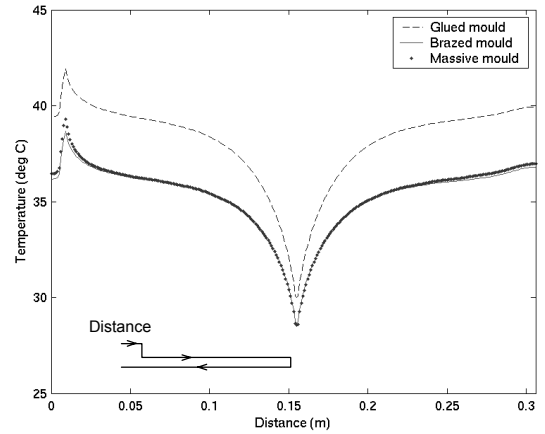


Fig. 5. Temperature distribution on the mould cavity surface according to laminate assembly technique

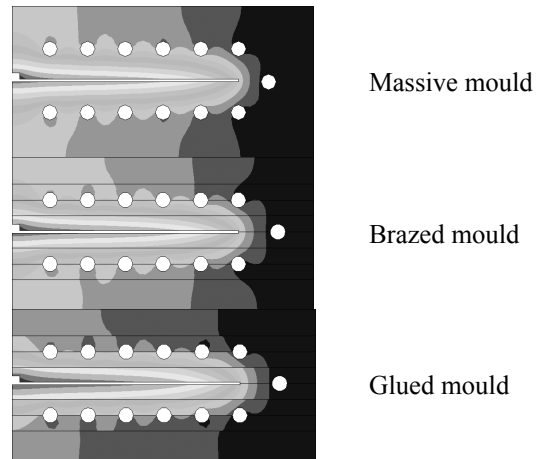


Fig. 6. Temperature distribution in massive and laminated moulds

4 POLYMER COOLING MODELISATION

4.1 Constitutive equations

The transient heat transfer equation (10) is applied to the mould and the polymer simultaneously.

$$\forall M \in \Omega_{i(i=M,P)} \quad \rho_i C_i \frac{\partial T}{\partial t} = \lambda_i \nabla^2 T \quad (10)$$

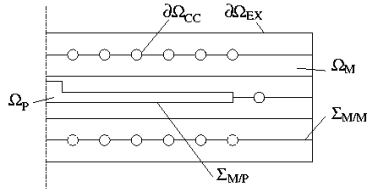


Fig. 7. Transient model domain definition

Boundary conditions on the mould channels and mould surface are the same as the steady-state model (5, 9).

For points located on the polymer surface or on the mould cavity surface, a new contact condition is introduced (11) where ΔT is the temperature difference between the polymer surface and the mould surface, $R_{M/P}$ is the thermal contact resistance at the mould/polymer interface and Φ is the heat flux crossing the interface.

$$\forall M \in \Sigma_{M/P} \quad \Delta T = R_{M/P} \Phi \quad (11)$$

Several studies have been carried out to determine the value of the thermal contact resistance [6,7]. This resistance is dependant on polymer pressure and shrinkage during the injection cycle. In order to avoid a coupled thermo-mechanical computation, the resistance is supposed to be constant in the model and equal to $10^{-3} \text{ m}^2 \cdot \text{K} \cdot \text{W}^{-1}$.

In our case, the initial temperature in the polymer is uniform and equal to the injection temperature $T_{inj} = 250^\circ\text{C}$.

$$\forall M \in \Omega_p \quad T(t=0) = T_{inj} \quad (12)$$

The initial temperature in the mould is homogenous and equal to the coolant temperature at the beginning of the first cycle. At the beginning of the following cycle, the initial temperature is equal to the final temperature of the previous cycle (13).

$$\forall M \in \Omega_M \quad \begin{cases} T(t=0) = T_\infty & 1^{st} \text{ cycle} \\ T(t=0) = T_{N-1} & N^{th} \text{ cycle} \end{cases} \quad (13)$$

4.2 Results

The results obtained here confirm the previous obtained using the steady-state model. At the cooling channel surface and at the cavity surface (fig. 8), the temperature obtained using the brazed mould is equal to the temperature obtained using the massive mould whereas the glued mould leads to a higher temperature.

In the polymer, the temperature obtained at the end of the cycle (for the same cooling time) is higher

with a glued mould. It confirms that heat transfer in the mould is less efficient with the glued assembly.

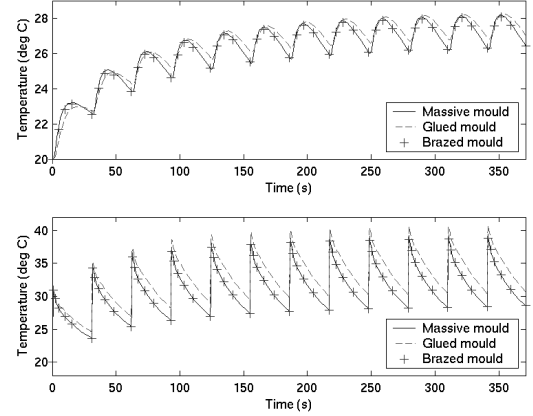


Fig. 8. Evolution of the mould temperature at the cooling channel surface and at the cavity mould surface

5 CONCLUSIONS

Steady state and transient models of the mould thermal regulation are detailed here and used to compare cooling channels geometry, mould making technique and bonding method. Results show the advantage of the brazed laminates making method that allow the realisation of complex shapes for the cooling system, without a modification of the heat conduction performance of the mould.

REFERENCES

1. Bryden B.G., Pashby I.R., Winpenney, D.I., Adams, C., Laminated steel tooling in the aerospace industry, *Materials & Design*, 21 (2000) 4001-403
2. Gley J., Barlier C., Cunin D. and Velnom L., From design to rapid tooling an application of Stratoconception : rapid tooling for foam casting, *EURO RP*, Paris (2001).
3. Pelaingre C., Barlier C., Denis G. and Levailant C., Moule d'extrusion-soufflage, réalisation d'outillage en Stratoconception : application à l'extrusion-soufflage, *EURO RP 2001*, Paris (2001), *in french*.
4. Menges G. and Mohren P., *How to make injection molds*, 2nd Edition, Hanser Publishers, (1993).
5. Xu X, Sachs E., Allen S., and Cima M., Designing conformal cooling channels for tooling, *Solid Freeform Fabrication Proceedings*, (1998).
6. Delaunay D., Le Bot P., Fulchiron R., Luye J.F. and Régnier G., Nature of convection between polymer and mold in injection molding. Part 1 : Influence of a non-perfect thermal contact, *Polymer Engineering and Science*, 40 (2000) 1682-1691.
7. Quilliet S., *Transferts thermiques à l'interface polymère-métal dans le procédé d'injection des thermoplastiques*, PhD Thesis, Université de Nantes, (1998), *in french*.
8. Himasekhar, K., Lottey, J., Wang, K.K., CAE mold cooling injection molding using three dimensional numerical simulation, *Journal of Engineering for Industry*, 114 (1992) 213-221.