HIGH PRESSURE BLOW MOLDING, AN INNOVATIVE WAY FOR DECREASING COOLING TIME

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Abstract

An essential cost factor of the blow molding process depends on the process- and cooling time. The heat transfer coefficient and the contact area between the blow-molded part surface and the mold cavity grows with an increased blow pressure. That leads to a decreased cooling time and consequently to a higher machine output rate and higher productivity. The paper is about the investigations of the cooling time reduction through high pressure blow molding and the determination of variation of time for the thermal contact resistance.

Introduction

The technical development of the blow molding process is characterized by increasing requirements on the economy of the process. The possibility to increase the productivity of the process by increasing the machinery delivery rate exists alternatively next to the reduction of used material. Because the cooling time takes the highest part of the production cycle, the biggest saving potential also exists here.

An intensifying of the cooling by the blow molding process can be reached by the following methods: internal cooling, post cooling and increase of the mold cooling. The first two mentioned points are very cost-intensive in the realization they are mainly used in special applications. The saving potential by an optimization of the mold cooling by using a high blow pressure is not used in the industrial practice until now.

Theoretical Background

The cooling process of blow-molded parts is physically recognized by the fact that the parison, which is inflated to the molded part, transfers heat. In doing so, the temperature of the molded part sinks. The heat transfer is possible because of the temperature difference between the hot molded part surface and the cooler mold. By exchanging the inflation air inside the molded part, heat can be additionally drawn from the internal side of the molded part. Thus the cooling is accelerated. The heat flow from the molded part must overcome three different thermal resistances on the way to the cooling agent from the mold side of the molded part surface (Fig.1).

The contact resistance between the molded part surface and the mold surface is characterized by the heat transfer coefficient, α_{cont} , which describes the thermal, not ideal contact between the both surfaces. α_{cont} is affected by the material pairing mold cavity - blow molded part, the melt temperature, the surface finish of the mold and the blow pressure. The second resistance is the mold material, which depends on the thermal conductivity of the mold, λ_M, as well as the arrangement and the geometry of the cooling channels. The resistance of the heat transfer from the mold to the cooling agent is described by the heat transfer coefficient, α_{CA}, and is determined by the cooling channel geometry, the cooling agent throughput and the cooling agent itself.

The mold k-value technically describes a heat transfer coefficient between the external mold part surface and the cooling agent. It sums up all of the thermal contact resistances between the mold part surface and the cooling agent and characterizes the quality of the thermal mold design. High k-values signal good heat conductivity and efficient mold cooling (1). The three thermal resistances are in analogy to the electric resistances in series (Fig. 1). Their sum is therefore constantly bigger than the biggest resistance on it's own. For the mold k-value (the inverse of the sum, Fig.1) that means that the smallest of the heat transfer coefficients, α_{cont}, λ_M/a_W and $\alpha_{CA,}$ have the greatest influence and that is always smaller then the smallest separate heat transfer coefficient. In further investigations it is established that the heat transfer coefficient, α_{cont} , has the highest influence on the k-value and the mold cooling (2). The cooling effect of the mold can thus be most effectively intensified by the improvement of this largest thermal resistance by a higher heat transfer coefficient, α_{cont}.

The typical blow molding process works with a blow pressure of $6{\cdot}10^5$ Pa, in this investigation the blow pressure will increase up to $40{\cdot}10^5$ Pa.

Determination of the Heat Transfer Coefficient

For the determination of the variation of time for the heat transfer coefficient (α_{cont}) the blow mold is equipped with various temperature sensors (Fig. 2). One thermocouple is placed very close (0,1 mm) to the mold cavity for measuring the mold surface temperature. The second one is placed 3,5 mm behind the first thermocouple; with the temperature difference of these both thermocouples the heat flow in the mold will be determined. An infrared sensor will be used for measuring the temperature of the molded part surface. Furthermore a pressure transducer measures the contact pressure between the blow-molded part and the mold cavity. A round bottle with a 1 liter volume is used in this investigation as blow-molded part.

Assuming an one-dimensional and steady heat flow by a linear temperature distribution the heat flow intensity can be calculated by (3):

$$\dot{q}'' = \lambda_M \cdot \frac{\vartheta_1 - \vartheta_2}{\delta_{1,2}} \quad [1]$$

ϑ_1 is the temperature which is measured by the thermocouple close to the cavity. ϑ_2 is the measured value of the second thermocouple. The thermal conductivity of the mold, λ_M, and $\delta_{1,2}$, the difference between the two tips of the thermocouples, are well known. The energy balance at the boundary layer "blow-molded part surface - mold cavity" must be valid at any time. That means that the heat flow intensity from Equation 1 must be the same like the heat flow intensity which transfers at the contact area between the blow-molded part and the mold cavity:

$$\dot{q}'' = \alpha_{cont} \cdot (\vartheta_{IR} - \vartheta_1) \quad [2]$$

ϑ_{IR} is the temperature of the blow-molded part surface which is measured by the infrared temperature sensor. The equation for the heat transfer coefficient (α_{cont}) concludes from the Equations 1 and 2:

$$\alpha_{cont} = \frac{\lambda_M \cdot (\vartheta_1 - \vartheta_2)}{\delta_{1,2} \cdot (\vartheta_{IR} - \vartheta_1)} \quad [3]$$

The thermal conductivity of the mold and the difference between the two tips of the thermocouples are well known, so that the heat transfer coefficient can be determined by measuring the different temperatures.

Investigations and Results

Investigations with different blow pressure were executed. The blow pressure is increased from $6 \cdot 10^5$ Pa to $12 \cdot 10^5$ Pa, $18 \cdot 10^5$ Pa, $24 \cdot 10^5$ Pa until $40 \cdot 10^5$ Pa. The wall thickness of the blow-molded parts lies in two different experimental series - at 1,2 mm and 2,2 mm. Furthermore the investigation will be conducted with polished, glassblasted and sandblasted mold surfaces. The possible heat flow rate is a function of the effective contact area, that means the area with an ideal contact between the melt and the cavity. A polished mold surface has large plane contact areas, but through the poorer venting will arise air cushions as insulating layers. Black pigmented high density polyethylene (PE-HD) is used for test material.

Fig. 3 shows a typical variation of the heat flow intensity and of the heat transfer coefficient with time. The heat flow increase by the time the parison is pushed against the cooled mold surface and converges against a steady value. The heat transfer coefficient also increases at the beginning of the parison inflation, but it converges more slowly against the steady value. This time-lagging increase is explainable with the measure-lags of the infrared sensor and of the thermocouples. On the other hand the determination equations for the heat flow intensity and the heat transfer coefficient are only valid for a steady thermal conductivity. In the blow molding process is an unsteady thermal conductivity present especially at the beginning of the parison inflation (4).

Influence of the Blow Pressure

An average value can be figured out by integration of the heat transfer coefficient (α_{cont}) over the blow time or cooling time. Fig. 4 shows the heat transfer coefficient, which is averaged over the cooling time, in dependence of the different blow pressures. The heat transfer coefficient increases with higher blow pressure, that leads to decreased cooling times at the same demolding temperature (65°C) (Fig. 5).

Influence of the Mold Surface

Fig. 5 points also out that the cooling time for the different mold surfaces depends on the blow pressure. The shapes of the curves are similar but however differ in their absolute values of the cooling times. The glassblasted mold surface shows the best results followed by the sandblasted and the polished mold surface. An increased surface quality leads not automatically to an improved heat transfer, because of the poorer venting between the parison and the mold cavity. In this investigations different mold surfaces do not lead to measurable differences of quality at the blow-molded part surface.

Fig. 6 shows the saving potentials by using the different mold surfaces. The cooling time reduction is percentage configured, based on the reference values for the main blow pressure ($6 \cdot 10^5$ Pa). A doubling of the blow pressure from $6 \cdot 10^5$ Pa to $12 \cdot 10^5$ Pa leads to cooling time savings of 10,3 % (glassblasted), 13,7 % for the sandblasted and 16,7 % for the polished mold surface. The cooling time savings are between 21,7 % and 32,8 % for an increased blow pressure to $24 \cdot 10^5$ Pa.

Influence of the Wall Thickness

The blow-molded parts are produced with two different wall thickness by using the glassblasted mold surface. The wall thickness increases from 1,2 mm to 2,2 mm by doubling the die gap. The other boundary conditions (e.g. screw speed) should be constant, therefore it is necessary to extend the cycle time by a mold waiting time. The open mold waits until the extruder conveys the necessary amount of melt and the minimal parison length is reached.

Fig. 7 shows the influence of the blow pressure on the cooling time for two different wall thickness. The influence of a higher blow pressure decreases with an increased wall thickness. A doubling of the blow pressure leads only to a cooling time reduction of 3,8 % for a wall thickness of 2,2 mm instead of 10,3 % for 1,2 mm. An increased blow pressure on $24 \cdot 10^5$ Pa presents a 8,0 % decreased cooling time instead of 21,7 % by producing the small wall thickness (1,2 mm).

Because of the higher internal material stiffness the thicker blow-molded part wall is not able to transfer the higher blow pressure optimally into an increased effective contact area, this is one reason for the smaller cooling time reductions. A further reason is the shrinkage characteristics of the polymer material. The blow-molded part shrinks by cooling and wants to detach from the mold cavity. For thinner blow-molded parts the internal pressure is high enough to compensate the shrinkage, with higher wall thickness the cooling stresses may be higher than the pressure forces and it leads to more air areas as insulating layers. The detaching process of the blow-molded part increases with the higher expansion capacity of the air between the blow-molded part and the cavity, because the air warms up by contact with the hot blow-molded part surface and so the specific volume increases.

Conclusions

The investigations to the influence of the blow pressure on the cooling time have shown that high savings in the cycle time of the whole extrusion blow molding process are reached with a constant product quality by simple modifications at the blow molding machine. The maximum of the cooling time reduction is up to 33 % in these investigations. The lowest absolute cooling times will be reached by using glassblasted mold surfaces, because of the good venting and high contact areas between the blow-molded part and the mold cavity. By using the different mold surfaces varying qualities of the blow-molded part surface could not be measured. The influence of the cooling time reduction is higher for blow-molded parts with smaller wall thickness.

Nomenclature

a_{Wall}	mold wall thickness
$\dot{q}''$	heat flow intensity
ϑ_{ca}	cooling agent temperature
ϑ_{cw}	cooling channel wall surface temperature
ϑ_{IR}	temperature of the blow-molded part surface measured by the infrared temperature sensor
ϑ_{mw}	temperature of the mold wall surface
ϑ_{mp}	temperature of the molded part surface
ϑ_1	temperature of the mold wall surface, measured by thermocouple 0,1 mm to the cavity
ϑ_2	temperature of thermocouple 0,36 mm to the cavity
$\delta_{1,2}$	difference between the two tips of the thermocouples
α_{CA}	heat transfer coefficient, from the mold to the cooling agent
α_{cont}	heat transfer coefficient between the blow-molded part surface and the mold surface
λ_M	thermal conductivity of the mold

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Key Words

high pressure blow molding, cooling time reduction, heat transfer coefficient

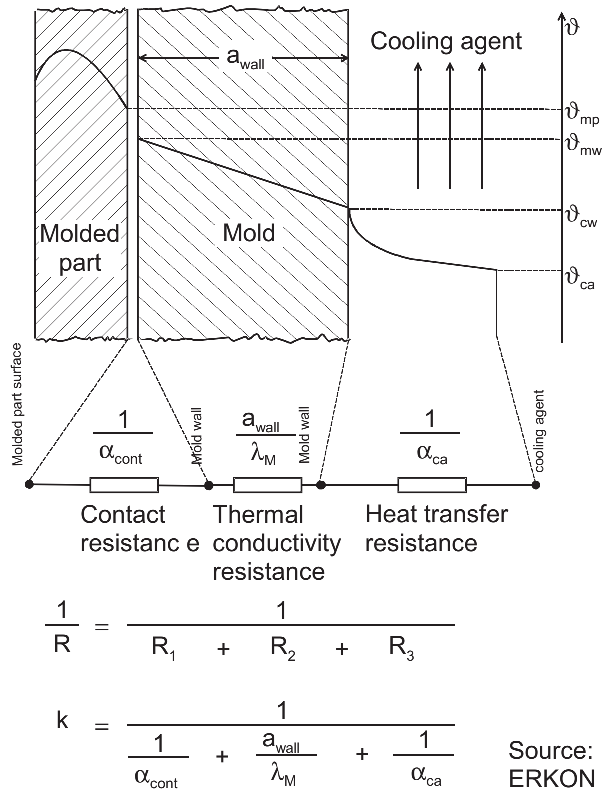

Figure 1: Mold cooling`s Heat Contact Resistance

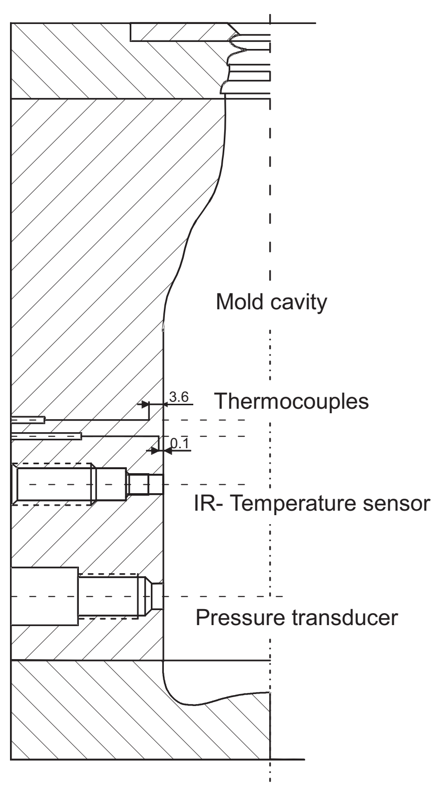

Figure 2: Blow Mold with Sensoric

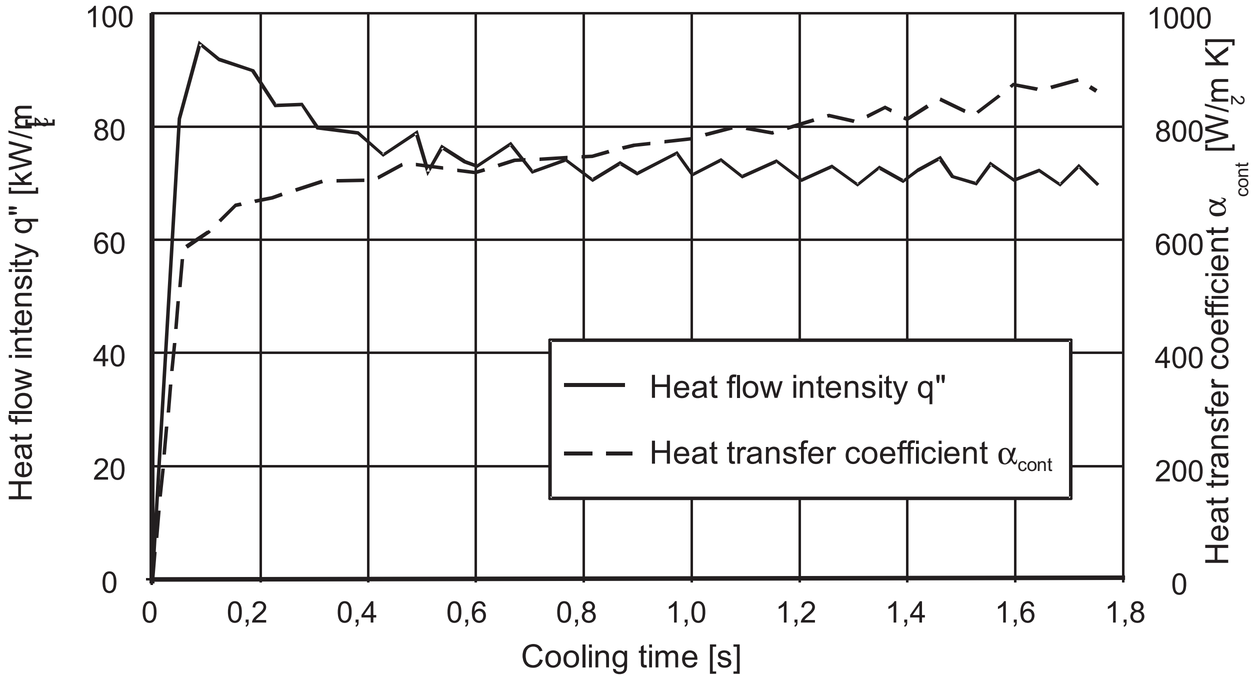

Figure 3: Determined Heat Flow Intensity and Heat Transfer Coefficient

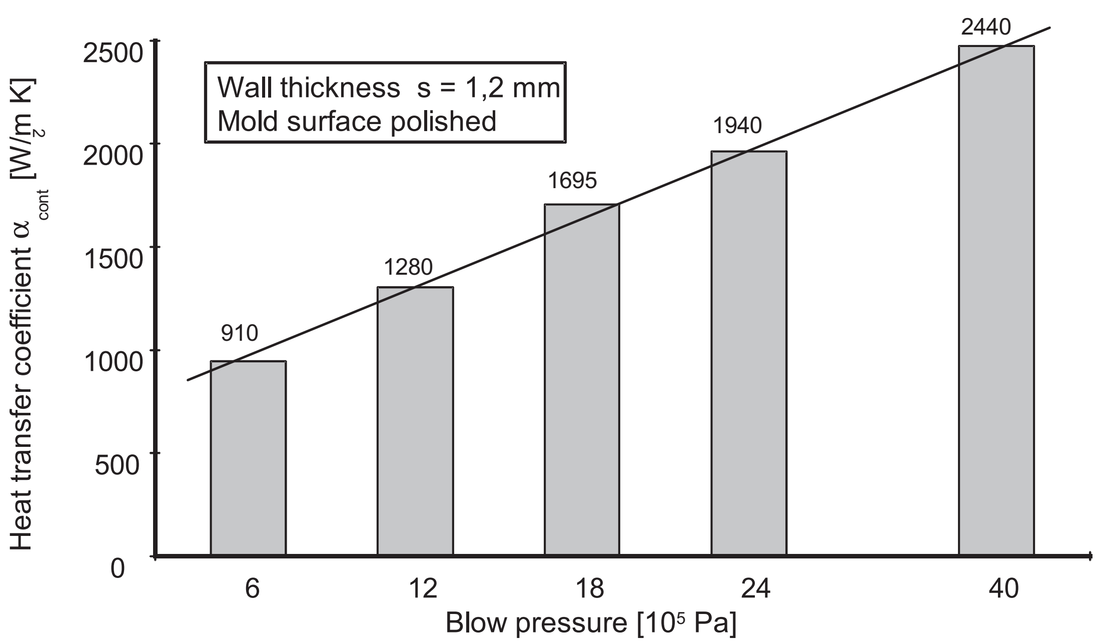

Figure 4: Heat Transfer Coefficient in Dependence of the Blow Pressure

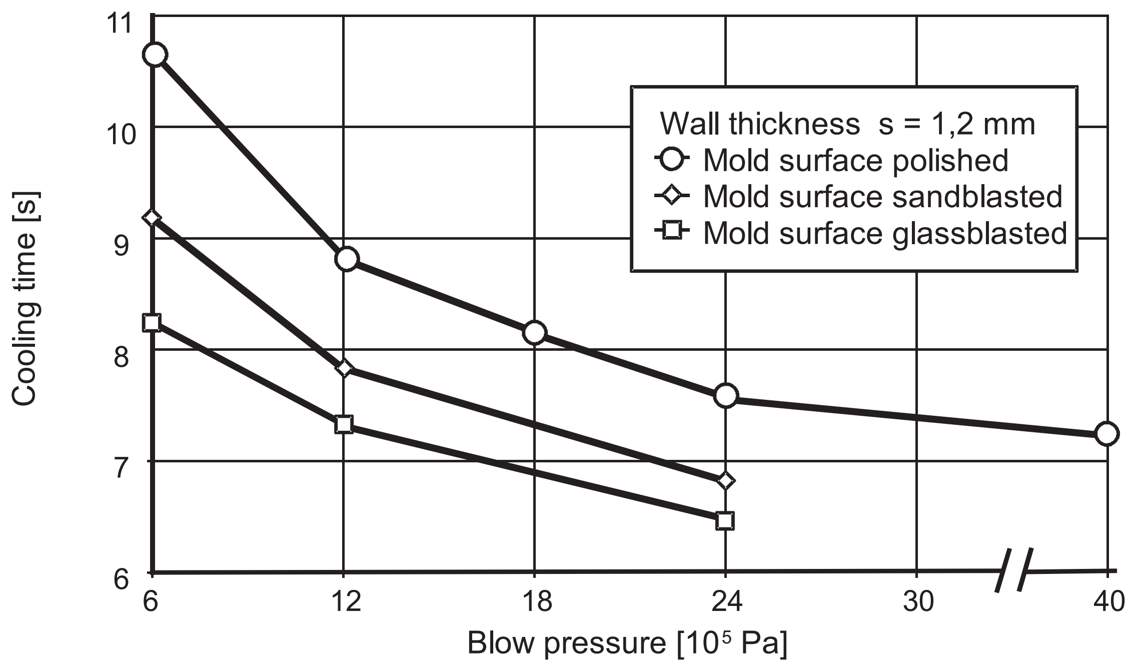

Figure 5: Cooling Time in Dependence of the Blow Pressure and Mold Surface

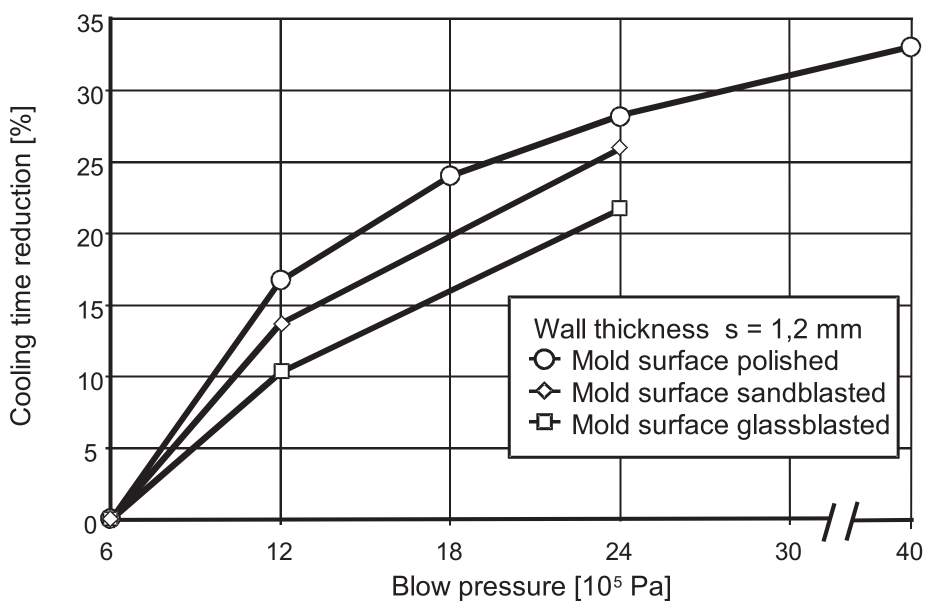

Figure 6: Cooling Time Reduction in Dependence of the Blow Pressure based on 6 10 Pa

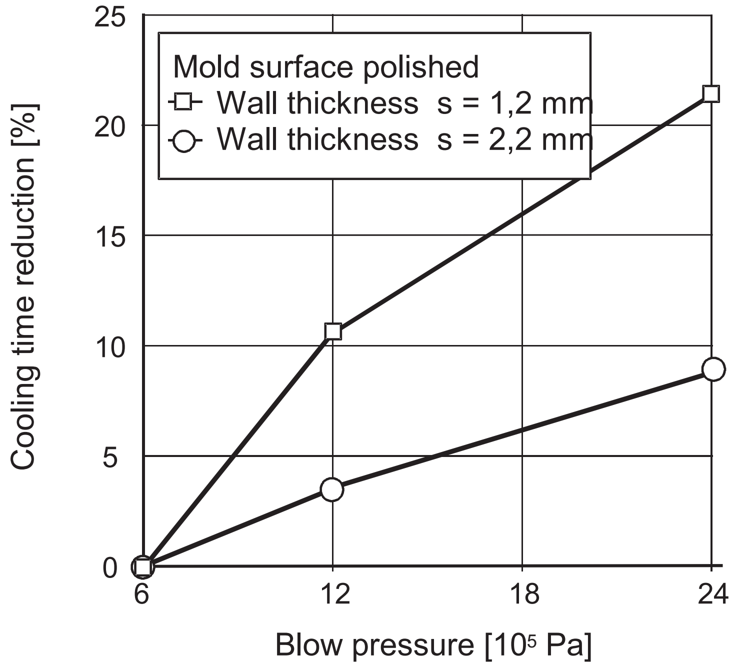

Figure 7: Cooling Time Reduction in Dependence of the Blow Pressure and Wall Thickness