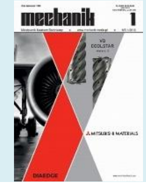

How to cite this article:

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Title of article: „Wpływ parametrów nastawnych i geometrii układu dolotowego na nagrzewanie wskutek ścinania" ("Influence of process parameters and runner geometry on shear heating effect")

Mechanik, Vol. 91, No. 1 (2018): pages 36–38

DOI: https://doi.org/10.17814/mechanik.2018.1.6

Influence of process parameters and runner geometry on shear heating effect

Wpływ parametrów nastawnych i geometrii układu dolotowego na nagrzewanie wskutek ścinania

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Shear heating effect that occurs in melted polymers can cause serious quality problems with production of injection molded parts. The source of this effect is high viscosity of polymers and low thermal conductivity what leads to significant temperature gradients at the cross section of runners. In this work the influence of processing parameters on this phenomenon for difference runner diameters and lengths was presented for two polymers that have different thermal sensitivity

KEYWORDS: plastics, shear heating, shear induced flow imbalance, runner design

Plastics are high-molecular compounds with long chains. Due to the ease of molding, low density and favorable mechanical properties, they are used as construction materials in industry. In comparison with other materials, they are plasticized at relatively low temperatures. In the plasticized state, they are treated as non-Newtonian fluids [1]. Plastics are characterized by viscoelasticity (which means that they retain some of the elastic properties during flow) and shear thinning (their viscosity decreases with increasing shear rate) [2].

The viscosity of plastics strongly depends on the temperature. Sensitivity to temperature changes (understood as the dependence of the melt viscosity on the temperature) is greater or smaller depending on the type of material (e.g. polycarbonates are high, and polyolefins have low sensitivity) [3].

Viscosity is a measure of the friction of the internal liquid as it flows. Plastics are characterized by high viscosity, which means high internal friction while flowing. This friction causes dissipation – in the form of thermal energy – of the work done by the pressure that is needed to flow the material. This phenomenon is called heat generation due to shear (shear heating effect). It causes a local increase in temperature in the polymer stream, which in extreme cases can lead to degradation of the material and the formation of local burns. The locality of this effect results from the very low thermal conductivity of plastics, which are thermal insulators. At the place of the highest shear, there is a significant local temperature increase (fig. 1).

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To avoid this, it is recommended to raise the plasticizing temperature of the material so that the possible local temperature increase due to the shear would be smaller.

The heat transport equation including the member responsible for generating the heat is as follows [4]:

$$\rho c_p\left(\frac{\partial T}{\partial t}+\boldsymbol{u}\cdot\nabla \mathrm{T}\right)=-\left(\frac{\partial \ln \rho}{\partial \ln \mathrm{T}}\right)_p\left(\frac{\partial p}{\partial t}+\boldsymbol{u}\cdot\nabla \mathrm{p}\right)+\nabla\cdot(\mathrm{k}\nabla \mathrm{T})+2\eta\dot{\gamma}^2$$

where: t – time, u – speed, p – pressure, T – temperature, ρ – density, c_p – specific heat, k – thermal conductivity, η – dynamic viscosity, γ – shear rate.

As it can be seen, dependence of the heat generation rate on viscosity is linear, and in the case of shear rate – square.

The consequence of the heating phenomenon is so-called the flow image due to shearing.

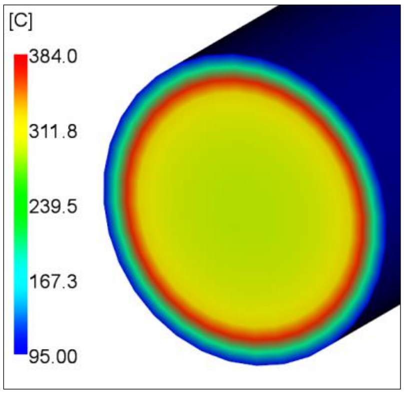

Fig. 1. Distribution of the temperature of the material on the intake manifold cross-section with a diameter of 6 mm for Lexan PC LS polycarbonate, with a plasticizing temperature of 305°C

Flow imbalance

In industrial practice, multi-cavity injection molds are used to increase production efficiency. To avoid production problems, they are constructed in such a way that the most distant ends of the material-forming nests will flow at the same time. This is when the tool is geometrically balanced.

However, it may turn out that for some plastics, some of the sockets will fill faster, and some – slower. The reason for this may be a sudden local temperature increase due to shearing. This is a very unfavorable effect, making it difficult to obtain products of the required quality. This phenomenon also applies to single-use forms – as a result of changes in viscosity in certain places, the material flows much faster than in others, which results in changes in the nest filling profile and the formation of quality defects [5].

Description of the experiment

Autodesk Moldflow Insight 2018 software was used to analyze the phenomenon of flow imbalance caused by shearing. The calculations were carried out for two materials:

- PC (Lexan LS1) – with high sensitivity to temperature changes,
- PP (Moplen HP500N) – with low sensitivity to temperature changes.

The analysis focuses on the impact of injection speed (measured by the volumetric flow rate *v* in cm³/s) and the temperature of the material T_m (in °C) on the occurrence of the heating effect of the material, leading to an offset of the shear induced imbalance. These two parameters were chosen, because the shear rate (depending on *v*) and the temperature of the material have a fundamental influence on the viscosity of the material. The volume flow rate was 50, 100 and 200 cm³/s, respectively, and the temperature effect was examined by reducing and increasing the base temperature of the material (235 °C for PP and 300 °C for PC, respectively) in each case by 10 °C.

The analysis was carried out for different diameters of inlet channels – from ⌀4 to ⌀8 mm, because this factor alongside the linear speed of the alloy affects the shear rate. The system consisted of beam elements, constituting intake channels, and volumes with low flow resistance (cylinder with a diameter of 40 mm and a length of 100 mm), as shown in fig. 2. The length of the inlet channel *L* was 70, 170 or 270 mm depending on from the resistance of the material – if the required pressure exceeded the assumed maximum injection pressure (180 MPa), the length of the flow path was reduced. The diameters and lengths of the channels have been selected for PC polycarbonate as a material of higher viscosity [6].

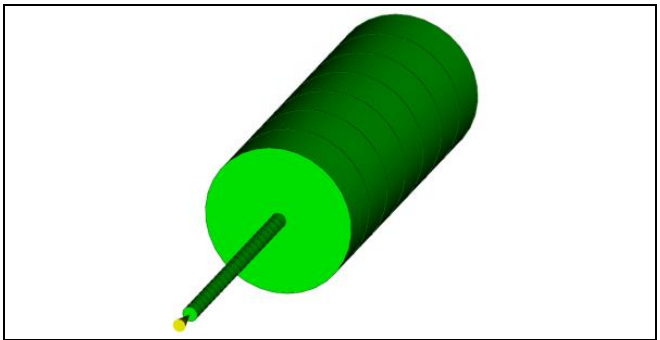

Fig. 2. Geometry of the tested system

Results

Fig. 3 and 4 show the temperature distribution of the material in the cross section of the inlet channel as a function of the *L* path (in mm), which material – PP and PC – overcomes when filling the injection mold for *v* = 100 cm³/s and 10 °C lower than the processing temperatures recommended for these plastics. The chart shows that the walls have a low temperature associated with the heat removal through the intake channel walls, and a short distance from the wall – a very high temperature. This coincides with the results of experimental studies on the location of the largest shear values in a circular channel [3].

The influence of adjustable parameters on temperature changes was further analyzed.

Polycarbonate is a material with high viscosity, therefore it requires the use of intake channels with a diameter larger than that of polyolefins. This is reflected in fig. 5 – in the case of relatively high flow velocities one can observe a very large temperature rise (the T_{destr} destruction temperature of approx. 480 °C is exceeded) and a pressure drop that prevents the analysis of longer flow paths. In the case of PC, a very large increase in T_{max} was observed with the increase of *v*. For polycarbonate, it is characteristic to strive for a certain maximum temperature in the flow path *L*, depending on the shear rate. As the diameter increases and the v decreases, this temperature limit value decreases (figs. 5–7). In the case of ⌀ equal to 4 and 6 mm, a relatively small influence of T_m on T_{max} was observed. It is only visible at ⌀8 mm with a large value of *v*. In fig. 6 and fig. 7, a flow point has been observed, above which a lower T_m resulted in a higher T_{max} – for the narrowest channel this point is invisible because the lower temperature practically from the very beginning generates higher T_{max} values.

Figs. 8–10 show the increase in maximum temperature T_{max} on the *L* road for PP. In the case of this material, the course is definitely different – no asymptotic aspiration of the material to a specific temperature in the tested range was observed. This may be due to the fact that higher shear rates are possible for this material.

In the entire examined range, regardless of the diameter of the channel, an increase in T_m caused that T_{max} had a higher value. This indicates a very small influence of temperature on the viscosity of the material. For a channel diameter of 6 mm for lower speeds, and for a diameter of 8 mm, it can be seen in the entire range that a change in T_m of 10 °C causes identical change in T_{max} – this means no positive temperature effect on heating reduction due to shearing.

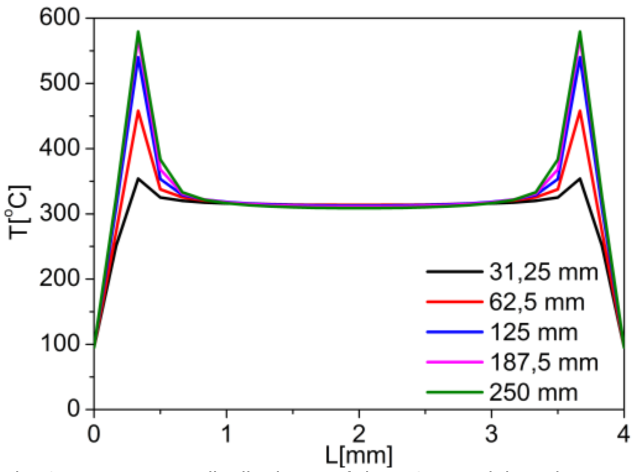

Fig. 3. Temperature distribution *T* of the PC material on the cross-section of the inlet channel along the channel diameter for different flow path

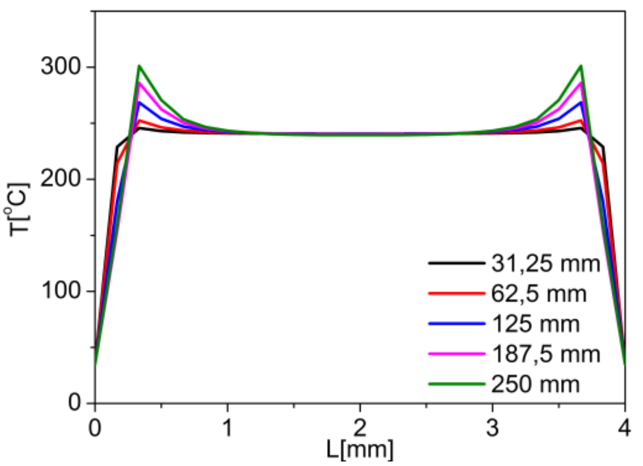

Fig. 4. Distribution of temperature *T* of PP material on the cross-section of the inlet channel along the channel diameter for different flow path

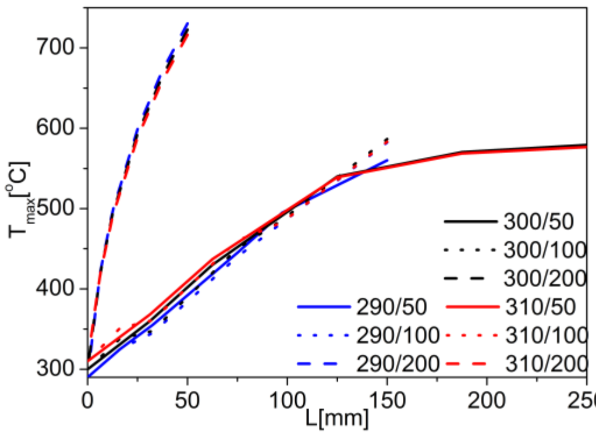

Fig. 5. Increase in the maximum temperature T_{max} in the intake duct with a diameter of ⌀4 mm on the road L for PC at different values T_m/v

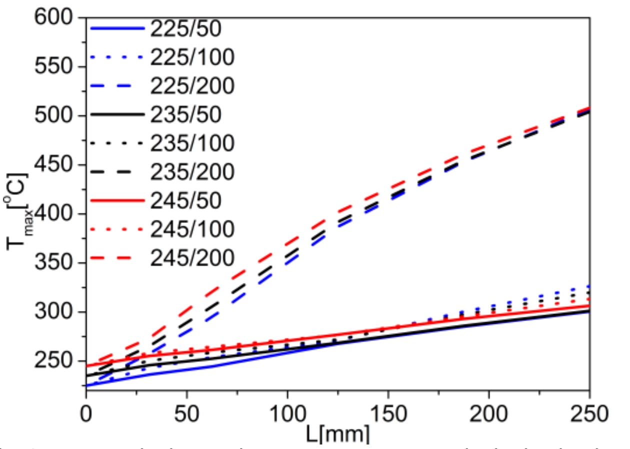

Fig. 8. Increase in the maximum temperature T_{max} in the intake duct with a diameter of ⌀4 mm on the road L for PP at different values T_m/v

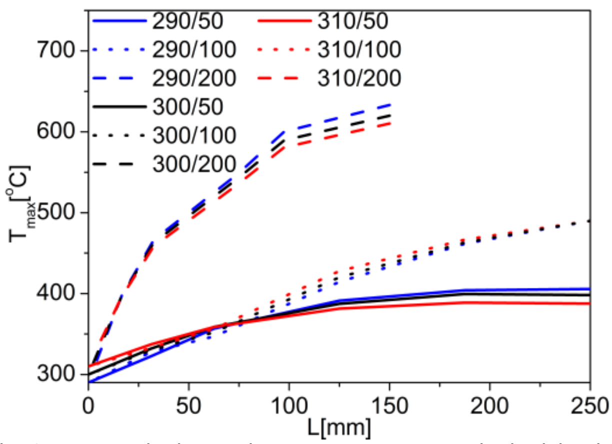

Fig. 6. Increase in the maximum temperature T_{max} in the inlet duct with a diameter of ⌀6 mm on the road L for PC at different values T_m/v

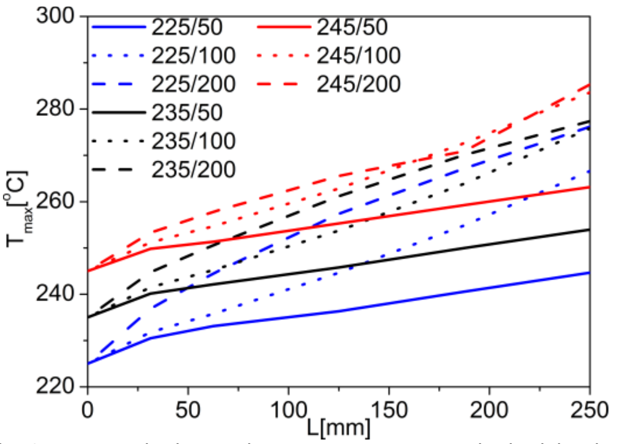

Fig. 9. Increase in the maximum temperature T_{max} in the inlet duct with a diameter of ⌀6 mm on the road L for PP at different values T_m/v

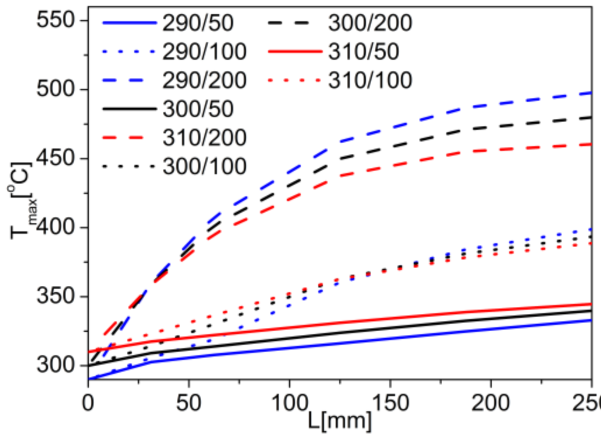

Fig. 7. Increase in the maximum temperature T_{max} in the intake channel with a diameter of ⌀8 mm on the road L for PC at different values T_m/v

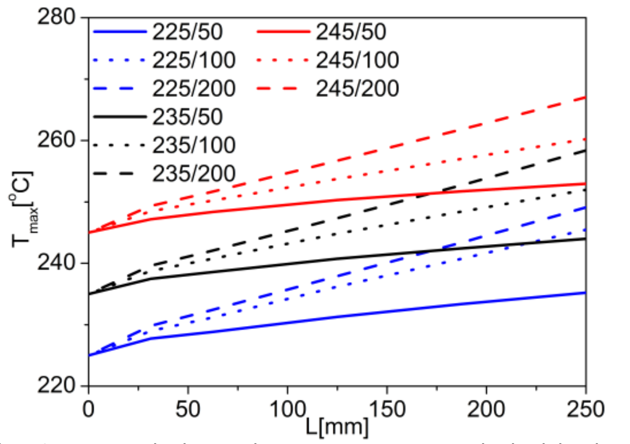

Fig. 10. Increase in the maximum temperature T_{max} in the inlet duct with a diameter of ⌀8 mm on the road L for PP at different values T_m/v

In the case of both materials, extremely unfavorable conditions (small diameter and high flow rate) caused a very high temperature rise – significantly exceeding the degradation temperature of the material (480 °C for PC [7] and 325 °C for PP [8]).

Conclusions

The amount of heat generated as a result of shearing the alloy and the possibility of its reduction depends strictly on the type of material. The basic way to avoid problems with degradation and burning is to reduce the injection speed or change the geometry of the intake system (shortening the length/increasing the diameter of the channels).

In the case of PC (fig. 6 and fig. 7), it was possible to lower the maximum value of the temperature reached during flow for the largest volume flow.

In addition, the temperature of the material has a negligible effect on this phenomenon.

Although the PC is a material with high thermal sensitivity [1], the significant effect of the melt temperature on the viscosity was noticeable only for the large diameter of the intake duct.

In the case of PP, raising the temperature of the material only led to an increase in the maximum temperature at the cross-section of the inlet channel. For this material, the change in processing temperature had a negligible impact in the studied range.

The key cause of local overheating is the low thermal conductivity of the materials, causing significant local increase in temperature (the generated heat is not quickly discharged to the channel wall). Increasing the thermal conductivity – thanks to the use of appropriate additives – should increase the average temperature while reducing local peaks.

Based on the obtained results, it was found that by appropriate selection of the geometry of the intake system (i.e. its diameter and length), it is possible to avoid too high temperature rise of the material, which is the cause of both degradation and imbalance in filling mold cavities.

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Translation of scientific articles, their computer composition and publishing them on the website www.mechanik.media.pl by original articles in Polish is a task financed from the funds of the Ministry of Science and Higher Education designated for dissemination of science.

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