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Visualization of melt flow lines in injection moulding

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ABSTRACT

Purpose: The examination of melt flow lines in injection moulded parts using a new method of flow visualization, which can be helpful in predicting weak areas in moulded parts created during cavity filling, was the purpose of this research.
Design/methodology/approach: The method of visualization used here is not classified yet. It allows to observe how the cavity is filled by looking at a specially created flow lines pattern. Normally they are defects and it is necessary to avoid them. In order to obtain such an effect on part surface the mould temperature was lowered, the holding stage was skipped (the holding pressure not applied), and injection time had to be short enough.
Findings: It was found on the example of moulded plastic parts of simple shape that the applied method of visualization allows to observe the filling process in mould cavity with good agreement to the theory and simulation results.
Research limitations/implications: The flow lines can be observed for some plastics like POM or PE when applying special processing conditions. The flow conditions are not the same as in a typical injection moulding process.
Practical implications: This method can be used for melt flow examination in the case of more complicated cavities and can help when having some problems in processing because of part design, for example improper weld line location.
Originality/value: Usually visible flow lines on part's surface are treated as a defect. In this paper it is shown that it can be an easy method of flow visualization.
Keywords: Plastic forming; Flow visualization; Injection moulding

1. Introduction

The melt flow in injection mould through the sprue, runners and gate to the cavity (or cavities) is no steady and non isothermal and depends on many factors connected with processed plastic, injection mould, injection machine and process conditions. The plastic and machine are usually factors determined by moulded parts' manufacturers and consumers but the change in processing conditions and in the design and manufacturing technology of mould allows to control the melt flow in mould runners to obtain parts with expected morphology, properties, shape, dimensions and surface. Melt flow in runners and gates should assure the laminar and total filling of the cavity, and in case of multicavity moulds – simultaneous filling of all cavities, to obtain repeatable parts of a good quality, at low decrease in melt pressure and temperature [1].

The important issue is the way and sequence of particular areas of mould cavity filling. The best situation would be if all border walls were reached by melt at the same moment what is very difficult or impossible to achieve in practice. The even cavity filling depends on the design of runner system (the number of injection points and their locations, the shape and dimensions of runners and gates), the accuracy of runner system manufacturing and the shape and dimensions of injection moulded parts (including the wall thickness and its distribution in the part). Sometimes it is necessary to control the melt flow in the cavity, for example in case of weld lines in the part. Weld lines should not be located in part areas which are under load or, because of aesthetic reasons, in places which are visible during their using.

It is very important to understand the possibilities of controlling rheological phenomena during melt flow in a mould because of economical reasons (decrease in material waste, shorten the injection cycle time) as well as because of quality requirements of moulded parts. The increasing requirements connected with injection moulding process quality and efficiency make monitoring and control of injection process stages a necessary thing. It is therefore useful to make research, both simulation and experimental, of phenomena occurring during melt flow in an injection mould. Such research should make easier the evaluation of injection moulding efficiency which is evaluated by physical and usage properties as well as surface properties of moulded parts.

The target of numerous research conducted with the use of numerical simulation of process is usually to obtain the pressure, temperature and shear rate distribution in a closed mould and investigation of melt flow front (or fronts) movement in cavity as well as determining the flow length in different injection moulding conditions. It is possible to calculate the pressure required for total cavity filling, clamping force after cavity filling, evaluating the optimal process conditions. Mathematical models were worked out which allow to evaluate the orientation of short fibers used as filler in injection moulded parts [2].

The experimental research, often combined with computer simulations, is of big importance. The following ways of experimental research of melt flow in mould can be distinguished:

- Moulds with transparent cavity walls [3]-[5]
- Short shots [1], [6]-[9]
- Introducing magnetic particles [10]
- Pigment as flow marker [7],[10] –[12]
- Filler as flow marker [9],[13]

In this paper the new method of melt flow investigation is proposed, in which injection moulding is performed without holding stage. Flow lines can be observed on a part surface in a few forms. They are usually part defects. In this article we named one of the defect forms as "flow lines", which is sometimes named "record grooves" [14] or "ripples" [15].

2. Experimental

In order to record the process of cavity filling an injection mould with simple shaped cavities was used and injections were done by such processing parameters, that flow lines occurred on parts' surface.

2.1. Material

Polyoxymethylene (POM) was used for investigation. The grade SNIATAL M8 with MFR = 48 g/10 min. (2.16 kg, 230ºC) was produced by Rhodia.

2.2. Machine

KRAUSS MAFFEI KM 65/160/C1 injection moulding machine was used for injection process. The maximum clamping force is 650 kN. The screw of plasticizing unit is of 30 mm diameter.

2.3. Injection mould

The moulded parts come from an experimental 16-cavity injection mould, described in earlier papers [6]-[9]. The parts are small plates of the shape and dimensions shown in Figure 1.

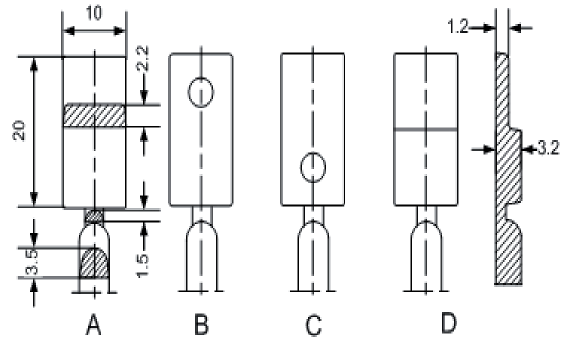

Fig. 1. Injection moulded parts with gates and runners

Parts A, B and C are of thickness 2.2 mm. Part D is stepped with two thickness values: 1.2 and 3.2 mm. Parts B and C have holes to form weld and meld lines.

2.4. Processing conditions

In order to obtain the flow lines special processing conditions were chosen. Especially mould temperature was too low for common POM injection processing:

- melt temperature: 180 ºC
- mould temperature: 30 ºC
- injection velocity: 10 and 120 mm/s
- holding pressure: 0

It was important to skip holding stage of injection moulding cycle (holding pressure = 0).

2.5. Flow lines recording

Flow lines were created during injection moulding process. They are visible on one side of the parts. The part surface was observed in reflected light using optical microscope and the pictures of surface were taken. The images presented in this article are negatives in black and white colours.

The results of experiments were compared with computer simulations of a filling stage made using Moldflow Plastics Insight, release. 4.1, software.

3. Results and discussion

3.1. Flow lines

The way of cavity filling is recorded by flow lines. The flow lines occurred more clearly on one surface of cavity which is formed by flat mould plate (Figure 2).

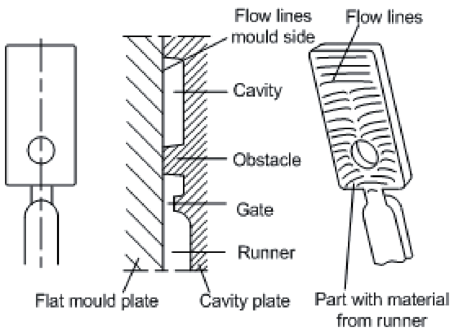

Fig. 2. Flow lines location on the part surface

The comparison of cavity filling predicted by simulation and shown by flow lines obtained from experiments is presented in Figure 3. The flow pattern is similar in both cases except for the area just after the gate. The simulation result does not show the stream coming directly from the gate. The finite element method used for calculation does not consider such flow behaviour because of necessary simplification of a modeling process. Jetting, which is not accepted phenomenon during filling, can not be shown by simulation software.

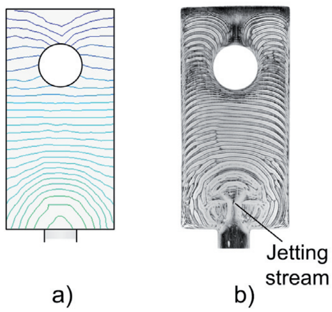

Fig. 3. Comparison of filling process simulated in Moldflow (a) and recorded by flow lines in experiments (b)

Experiments showed another phenomenon not predicted by simulation software – secondary flow in cavity corners. It was described in [16] for the opposite case – the inflow from wider to narrower channel. In the presented case melt flows out from the narrow gate into the wide cavity – Figure 4.

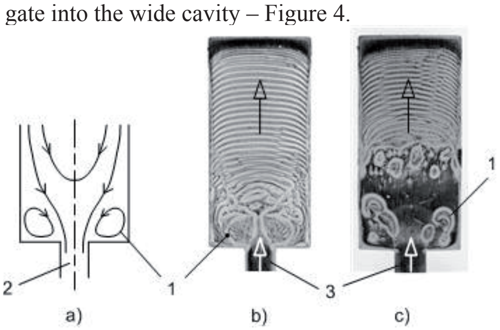

Fig. 4. Secondary flow: a) polymer inflow into a narrow channel [16], b, c) polymer inflow from the narrow gate into mould cavity at injection time 0.15 s (b) and 0.25 s (c); 1 – secondary flow lines, 2 – narrow channel, 3 – gate

3.2. Weld- and meld lines

Flow lines in parts B and C (Fig. 1) visualize the weld and meld lines formation in parts. For the cavity with simple shape and central located obstacles it is obvious, where weld line is created. However, sometimes weld and meld lines are not visible in part, but they weaken the parts in certain areas. Weld line (part B) and meld line (part C) is shown in Figure 5.

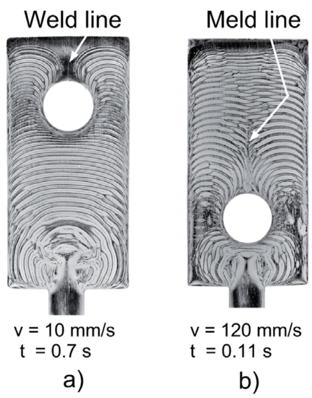

Fig. 5. Moulded parts with weld lines (a) and meld lines (b)

3.3. Cavity filling under pressure

Mould cavity is filled in the injection stage of a technological process. In this stage cavity is being filled. After melt flow front reaches all border walls (the cavity is filled up) the holding stage begins.

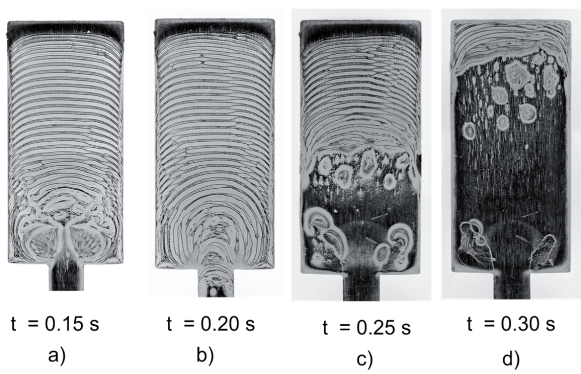

Fig. 6. Flow lines in parts obtained at different injection time

The melt pressure increases rapidly. If the process is conducted properly the holding pressure is applied at this moment, when cavity is being filled up.

In experiments holding stage was not applied and the parts were moulded with different injection time. The melt flow in the filled cavity was observed. When the time was sufficiently long, the flow lines disappeared. Figure 6 presents the change of flow lines with increasing injection time influencing the increase in melt pressure. What is noticeable – the disappearing of flow lines starts from the gate, where melt pressure is higher than at the flow end.

3.4. The influence of cavity thickness

The cavities of D shape have two stepped thickness. It was found that the flow lines have different patterns in both sections. In the first section, which is thicker (3.2 mm) than for parts A, B and C, longer jetting stream occurs. In the second section, which is thinner than other cavities (1.2 mm) the flow lines are closer together (Figure 7).

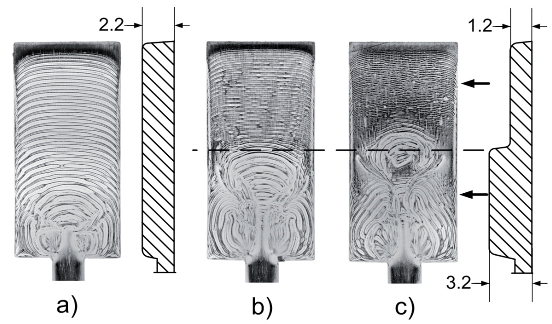

Fig. 7. Flow lines patterns in parts of different thickness: a) part A – injection velocity v=10 mm/s injection time t=0.8 s, b) part D – v=10 mm/s, t=0.7 s c) part D – v=120 mm/s, t=0.11 s

4. Conclusions

The possibility of observation of flow lines is important for filling investigation. It can help to understand and solve some problems with mould cavities filling to obtain parts of high quality. One of possible solutions can be the gate correction or, if it is possible, adding new injection point.

To sum up the experiment results:

- Flow lines can be used to check how the cavity is filled
- Computer simulation does not allow to predict all phenomena of the melt behaviour, e.g. jetting and secondary flow
- Weld and meld lines location can be checked with this method
- Flow lines occur only by some special processing conditions (low mould temperature, low melt pressure)

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