

Dynamic mechanical properties of parts from multicavity injection mould

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Received 03.04.2007; published in revised form 01.08.2007

Manufacturing and processing

ABSTRACT

Purpose: The examination of dynamic mechanical properties of injection moulded parts, obtained from different cavities of injection mould, was the purpose of this research. The parts were manufactured from polypropylene.

Design/methodology/approach: The testing method used was DMTA – “Dynamic Mechanical Thermal Analysis” – which is often used to determine the properties of polymers, blends and composites as well as the manufactured parts.

Findings: The differences in storage modulus E' and loss factor $\tan \delta$ of parts from particular mould cavities were found. The differences are caused by polymer flow and thermal conditions specific for each cavity.

Research limitations/implications: An injection mould with geometrically balanced runners was used for investigation. The differences in parts' properties occur for every injection mould, but they are dependent on the cavities layout and runners configuration.

Practical implications: The results of investigation provided the information that there are significant differences in parts' properties. Knowing that, the mould designers should take an effort to minimize the temperature differences in the mould and to assure the equal cavity filling.

Originality/value: Usually the naturally balanced runners were supposed to assure the equal filling for all the cavities. Lately some research was made which discovered that this is not true. There were some solutions of this problem proposed. All investigation was focused on simultaneous plastic flow into all cavities, but there were no investigation of parts' properties.

Keywords: Plastic forming; Injection moulding; Dynamic mechanical properties

1. Introduction

The feed system of injection mould plays the important role. It consists of sprue, runners and gates. All these entities are channels that melt flows to cavities through. The feed system design is important to achieve proper cavity filling during the injection phase of the cycle of injection moulding process [1]. The flow conditions in mould cavities affect the later parts' properties [2], so it should be controlled by optimized feed system design. The runners' dimensions are important to feed the cavities with melt of enough high temperature and pressure. Gate positioning is

also very important because it influences the location of weld lines in a part and it should be optimized [3] to obtain the loss of melt temperature and pressure as small as possible.

The feed system in multicavity injection mould should be designed so that all the cavities were filled simultaneously [4]-[6]. If this is achieved the flow into the cavities is balanced and the runners are called “balanced”. There are many runners' configurations in injection mould. Two main sorts of balanced runners systems are [4]:

- naturally (geometrically) balanced runners,
- artificially balanced runners.

In the past the geometrically balanced runners were supposed to be a good solution. However, in the last decade some research works were done which proved that there are some problems to obtain flow balance even in the traditional geometrically balanced runners [6]-[14]. The research was focused on flow imbalance and its counteraction rather than on the differences in parts properties. Thus there is a need to investigate how the filling imbalance influences injection moulded parts' properties.

2. Experimental

A multicavity injection mould was used for this investigation. Polypropylene was injected to the mould and the flow balance was checked using the short shots method. The morphology of parts from different cavities was investigated. Dynamic mechanical properties of parts were tested.

2.1. Material

Polypropylene (PP) was used for investigation. The grade MALEN P F-401 with MFR = 3.00 g/10 min. (2.16 kg, 230°C) was produced by PKN Orlen, Poland (now: Basell Orlen Polyolefins).

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 [13]-[15]. The parts are small plates of the shape and dimensions shown in Figure 1.

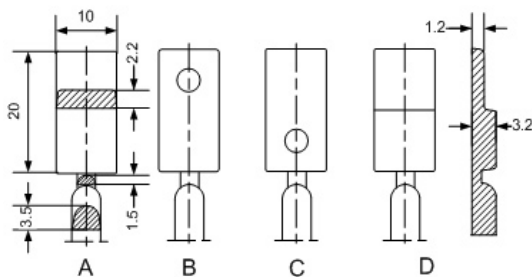


Fig. 1. Injection moulded parts with gates and runners

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. The layout of parts in the mould with the runner system is shown in Figure 2.

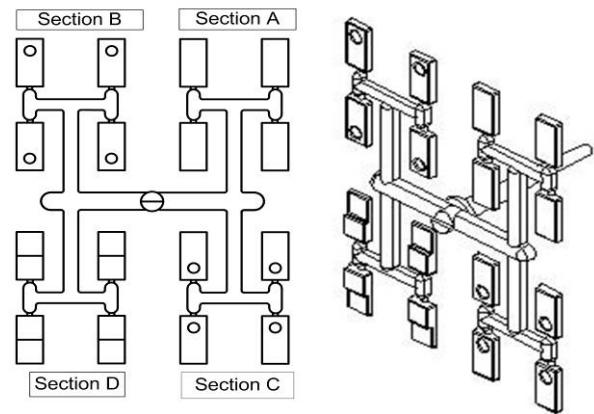


Fig. 2. Layout of parts in the experimental mould

2.4. Processing conditions

The parts were injection moulded at the following processing conditions:

- melt temperature: $T_i = 240\text{ }^\circ\text{C}$
- mould temperature: $T_m = 30\text{ }^\circ\text{C}$
- injection velocity: $v = 95\text{ mm/s}$
- holding pressure: $p_H = 40\text{ MPa}$

Shorts shots method was used to check how the cavities are filled. In this investigation the holding stage was skipped and injection time was adjusted short enough to obtain cavities not filled totally.

2.5. Microscopic investigation

Parts' morphology was investigated using optical microscopy. Samples of 15 μm thickness were microtomed using Anglia Scientific microtome and prepared for observations at Olympus BH-2 microscope in polarized light.

2.6. DMTA investigation

Samples for DMTA investigation were cut out from the injection moulded parts from mould section A, as shown in Fig. 3. Sample cross-section was 3.0 x 2.2 mm. The sample was tested using 3-point bending method with NETZSCH DMA 242C apparatus. The distance between supports was 10 mm. The tests were conducted with the frequency of 10 Hz. The samples were heated from $-70\text{ }^\circ\text{C}$ up to $150\text{ }^\circ\text{C}$ with the heating rate of $10\text{ }^\circ\text{C/min}$.

3. Results and discussion

3.1. Short shots

The injection moulding process parameters were changed to obtain short shots. The injection time t_i was short enough that

flow front didn't reach the end of a cavity wall and the holding stage was skipped. The cavities were not filled totally and the flow front advance showed the sequence of cavities filling. Despite using the geometrically balanced runners the cavities are not filled at the same time, but in a particular sequence. The cavities placed in the mould centre (numbered "1"), which is more heated by the sprue, are filled as the first ones.

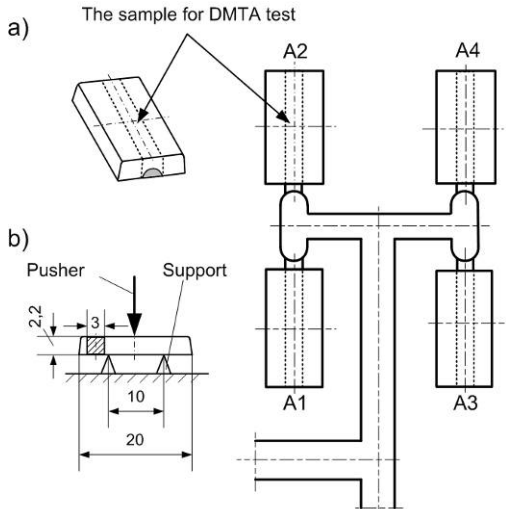


Fig. 3. Samples taken from parts moulded in section A

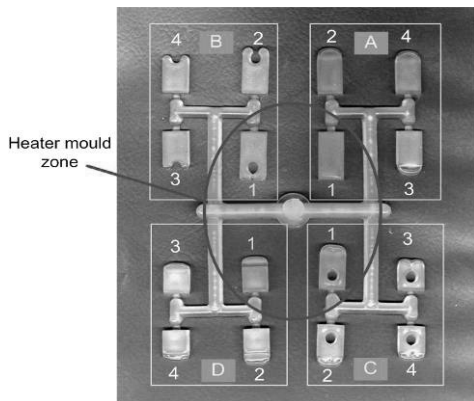


Fig. 4. Short shots made at injection time $t_i=0,55$ s, $T_m=30^\circ\text{C}$

In further investigation of properties (morphology, DMTA) the parts from section A were compared.

3.2. Morphology of injection moulded parts

The classical skin-core morphology was observed. The comparison of morphology for part A1 (cavity filled first in mould section A) and part A4 (cavity filled as the last one) is presented in Fig.5. In parts A1 wider transient zone was observed. Cavities A1 are placed in hotter mould zone and there are better conditions for polymer relaxation in core oriented zone. Since the parts from particular cavities differ in morphology, they are also supposed to differ in properties.

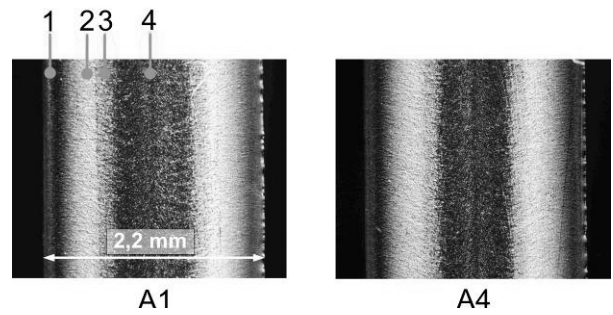


Fig. 5. Morphology of parts from cavities: A1 (left) and A4 (right) injected by mould temperature value $T_m=30^\circ\text{C}$; 1-skin layer, 2-oriented core zone, 3- transient zone, 4-non-oriented core zone

3.3. Dynamic mechanical properties

The results of DMTA tests are presented in Fig. 6. The curves of storage modulus E' and loss factor $\tan \delta$ versus temperature are plotted for all four parts from mould section A.

Storage modulus E' is decreasing with the temperature. There is a significant difference in E' between parts from different cavities. E' values are bigger for part A4, which were formed in cavities filled as last ones and placed in colder mould zone. Since in parts A4 the oriented core zone is wider (not relaxed as much as in parts A1) their mechanical properties are better.

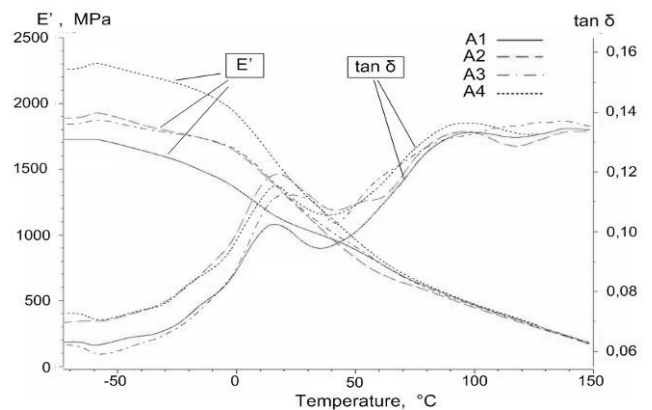


Fig. 6. Storage modulus E' and loss factor $\tan \delta$ versus temperature for parts coming from different cavities in mould section A

The difference of E' is significantly high for low temperature values (under 0°C) but also for common temperature of polymer parts exploitation ($20-30^\circ\text{C}$). In temperature 20°C this difference is 370MPa . This means that the polypropylene parts moulded at relatively low mould temperature have different mechanical properties depending on the cavity location in the mould.

The curves of $\tan \delta$ show the peak around temperature of 18°C . For this temperature value the relaxation of amorphous phase in polypropylene occurs. For $\tan \delta$ the differences between samples from particular cavities were also noticed. In the peak temperature the differences in $\tan \delta$ are about $0,013$.

4. Conclusions

Polypropylene parts from a multicavity injection mould with geometrically balanced runner differ in dynamic mechanical properties. The difference in storage modulus and loss factor was observed.

The reasons of these differences are: flow imbalance during mould filling and differences in mould temperature for the particular cavities. When small tolerance of injection moulded parts' properties is required, another runner system configuration in the mould should be used. It is also advised to place the cavities in the way that each part is under the same cooling conditions.

Acknowledgements

This work was financially supported from Polish Ministry of Scientific Research and Information Technology. Budget for science in years 2005-2006; Grant number 3 T08E 032 28

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