Archives of Materials Science and Engineering

Volume 30
Issue 1
March 2008
Pages 53-56

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Crystallinity of parts from multicavity injection mould

T. Jaruga*, E. Bociąga

Department of Polymer Processing and Production Management, Czestochowa University of Technology, Al. Armii Krajowej 19c, 42-200 Częstochowa, Poland

* Corresponding author: E-mail address: jaruga@kpts.pcz.czest.pl

Received 02.01.2008; published in revised form 01.03.2008

ABSTRACT

Purpose: The intention of this research was to test, if injection moulded polyoxymethylene parts, manufactured in different cavities of the multicavity injection mould with geometrically balanced runners, differ in crystallinity degree.

Design/methodology/approach: The values of crystallinity degree were calculated on the basis of DSC (Dynamic Scanning Calorimetry) testing method results (DSC curves).

Findings: It was found that there are differences in crystallinity degree for parts from particular mould cavities. The reason of this is the difference in thermal conditions, specific for each cavity.

Research limitations/implications: It is supposed that the parts from each multicavity injection mould would have differences in properties. However, it is always dependent on cavities and runners' layout. Since in this research a particular injection mould was used, the conclusions can not be directly extrapolated to other moulds. Each case requires its own analysis. Higher crystallinity degree will occur in parts obtained from areas of higher mould temperature.

Practical implications: The results of this investigation are important for mould designers, especially when moulds are used for precision injection moulding. It was proved here that differences in parts' properties can occur for multicavity injection moulds. In order to avoid this it is required to minimize the temperature differences in the mould.

Originality/value: Geometrically balanced runners in the mould were supposed to assure the equal filling of all cavities. The results obtained lately by other researchers have shown that this is not always true. That investigation was mostly focused on filling imbalance that leads for example to difference in weight of parts from different cavities. In this paper it was shown that not only weight of parts can differ but also other properties.

Keywords: Plastic forming; Injection moulding; Crystallinity degree

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Crystallinity degree of polymer is the percentage of crystalline phase in a sample of semi-crystalline polymer. It is dependent on thermal conditions during crystallization. In case of injection moulded parts melted polymer is injected from plasticizing unit into the injection mould where is then cooled and became solid. During the solidification the crystallization process occurs. The crystallinity degree of polymer in the moulded part is dependent on mould temperature and melt temperature. Both temperature values determine the cooling rate which is directly the reason of differences in crystalline structure. If the cooling rate is rapid, the conditions are not convenient for crystallization and more amorphous phase is formed. In case of slow cooling the time of keeping polymer in temperature required for crystallization is longer and this results in better formed crystalline structure.

As the consequence – the crystallinity of injection moulded parts can be influenced by processing conditions like mould temperature or melt temperature.

When the mould temperature is higher the crystallinity degree of moulded parts is also higher. This causes also higher density of parts. The heat treatment of moulded parts, which is sometimes used to improve their properties, is also the way of increasing the crystallinity degree. This feature of injection moulded parts influences directly their mechanical properties – parts of higher crystallinity degree have higher values of hardness, tensile strength, wear resistance and better dimension stability.

There are publications that deal with the influence of mould temperature on the crystallinity degree of injection moulded parts or their other properties [1]. However, usually they are focused on parts from single-cavity moulds. It is supposed that in multicavity moulds all parts have the same crystallinity, but, as it was proved in some publications, it can differ significantly across one part, for example being dependent on the distance from the gate (injection point). Considering this a question can be asked if the cavity location in the mould can impact crystallinity degree of parts.

In multi-cavity injection mould all cavities should be filled at the same time. If not, the time of crystallization for different cavities would be different. The runner system plays a very important role in injection mould, especially during mould filling phase [2]. It is always a big effort made by mould designers to balance the flow in runners – it means that all cavities are filled simultaneously. The runner system should be optimized [3].

Among runner systems in injection moulds two main kinds of balanced runners can be distinguished:

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

In artificially balanced runners the flow balance is achieved by design of runners cross-section. Since the flow length to the cavities is different, the runners leading to closer cavities should have smaller cross-section. In this way melt reaches all cavities at the same time. In some cases it is possible to design only different cross-section of gates.

Geometrically balanced runners are designed so that the summary length of runners leading to each cavity is the same. This solution does not require different cross-section of runners, but has also disadvantage: more scrap in case of cold-runner moulds – the total volume of material solidified in runners is significantly bigger [4]. In the past the geometrically balanced runners were supposed to be a good solution considering the flow balance. However, some research works from the last decade proved that even in this solution some problems with achieving the flow balance can occur [5-[12]. The works were focused on flow imbalance and its counteraction rather than on the consequences, that are the differences in parts properties. The investigation of the influence of cavity filling imbalance on injection moulded parts' properties is needed. It will allow to estimate if differences between parts are so significant that correction of the mould is required.

In practise, filling phase in injection moulding takes only a while – usually a fraction of a second up to several seconds. Thus the filling imbalance has little influence on crystallization. More important can be the difference in mould temperature across the cavity.

In this paper the injection mould with geometrically balances runners was tested. As it was shown in previous papers, the geometrical balance did not assure the real balance during cavity filling [13]. The flow imbalance together with the differences in mould temperature contributed to differences in parts' properties, like the structure and dynamic mechanical properties [13],[14]. In this paper the focus was on difference in crystallinity between parts from particular cavities.

2. Experimental

For this investigation a multicavity injection mould was used. It was also used for investigation of other parts properties, as it was described in previous publications [13],[14]. Polyoxymethylene (POM) was injected into the mould and the crystallinity degree of parts from different cavities was calculated on the basis of DSC curves.

2.1. Material

Polyoxymethylene (POM) was used for investigation. The grade was Sniatal M8 from Nyltech, Italy, with MFR = 48 g/10 min (2.16 kg, 190ºC).

2.2. Machine

The mould was fixed in the injection moulding machine KRAUSS MAFFEI KM 65/160/C1 of the maximum clamping force 650 kN and the plasticizing unit with the screw of 30 mm diameter.

2.3. Injection mould

The moulded parts were manufactured in the experimental 16-cavity injection mould, described in earlier papers [13]-[18]. The parts are small plates (10.0x20.0x2.2mm) grouped in 4 sections, marked A, B, C and D. The layout of runners and cavities is shown in Fig. 1 on the example of short shots result, presented in previous publications. It was found that despite geometrically balanced runner system the cavities are not filled at the same time. The cavities placed around the sprue (numbered with "1") are filled first. This area is exposed to higher local mould temperature, as it was proved in [16]. The sequence of cavities filling in each section is shown in Fig. 1 by numbers 1-4.

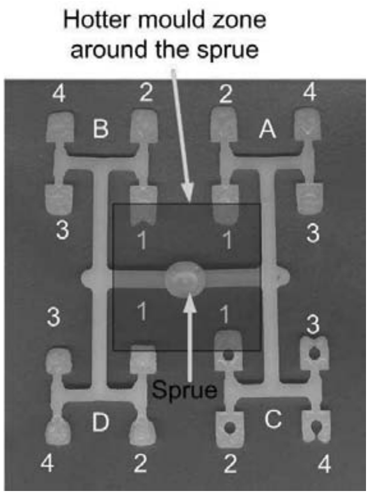

Fig. 1. Short shots into the multicavity mould – inequality of cavities' filling; A-D: cavity sections; 1-4: filling sequence

2.4. Processing conditions

The processing conditions used for injection moulding are as follows:

- melt temperature: T_{inj} = 210 ºC
- mould temperature: T_m = 35, 65 and 95 ºC
- injection velocity: v = 32 mm/s
- holding pressure: p_H=30 MPa

2.5. DSC tests

DSC test were carried out with the NETZSCH Phox DSC 200P apparatus.

The small pieces of material were cut out of the parts like it is shown in Fig. 2. The samples were taken to DSC measurements with the skin-layer so the results present the average crystallinity across the part thickness, together with this layer. The mass of parts was 20 ± 2 mg. The parts were taken from one section of the mould. Fig. 2 shows the numeration of cavities in this section according the sequence of their filling (1-4). Five samples from each cavity were taken for DSC tests.

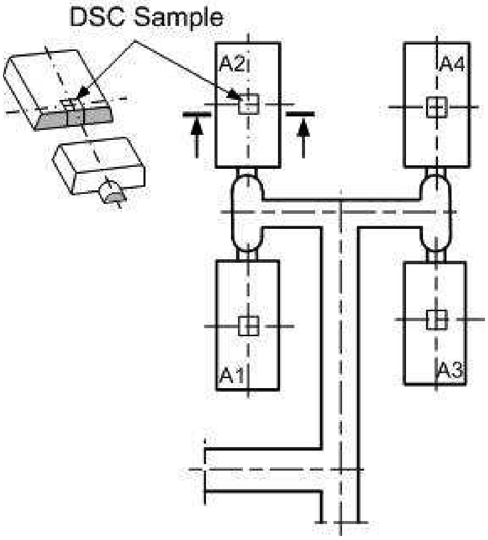

Fig. 2. Cutting out of samples from injection moulded parts

During DSC tests the temperature was increased with the rate of 10°C/min. After obtaining the DSC curves the crystallinity degree S_k was calculated. It was defined as below:

$$S_k = \frac{\Delta H_p}{\Delta H_c} 100,\%$$

where

ΔH_p - melt enthalpy of tested polymer [J/g]

ΔH_c - melt enthalpy of fully crystalline material (reference) [J/g]

3. Results and discussion

3.1. DSC curves

The obtained curves were similar for samples coming from parts from the same cavity. Three exemplary DSC curves of samples from part no. A1 are presented in Fig. 3. The melt enthalpy for each curve was calculated using the NETZSCH DSC software.

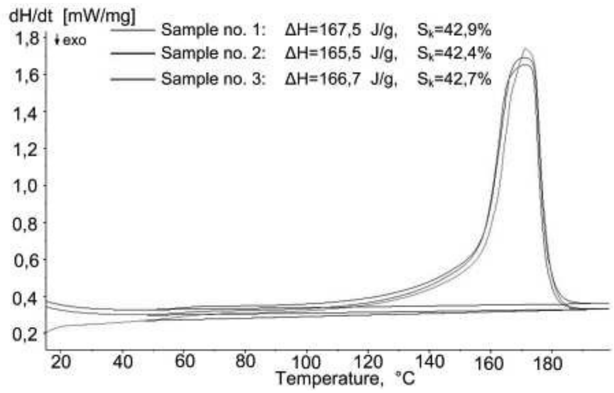

Fig. 3. Exemplary DSC curves

3.2. Crystallinity degree

The results of crystallinity degree calculation for parts obtained at different mould temperature are presented in Fig. 4. Beyond discussion is that for each cavity the mould temperature, that was adjusted at values: 35, 65 and 95°C (measured and controlled in one point), has significant influence on this property. The local mould temperature impact is also visible. The crystallinity degree values are the highest for cavities no. 1, exposed to higher local mould temperature.

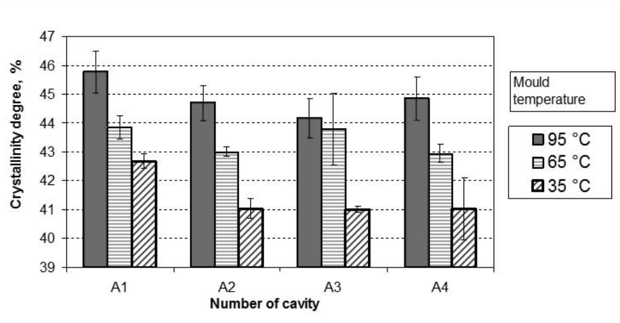

Fig. 4. Crystallinity degree for samples from different cavities

4. Conclusions

Polyoxymethylene parts from a multicavity injection mould with geometrically balanced runner differ in crystallinity degree. The main reason of it is different mould temperature for the particular cavities.

It is important to place the cavities in the way that each part is under the same cooling conditions. Otherwise the problems in parts quality can occur like different shrinkage, warpage and other properties. Such a problem is caused by particular cavities layout that determines exposition of some cavities for higher temperature coming from heated sprue. When small tolerance of injection moulded parts' properties is required, another runner system configuration in the mould should be used or local cooling conditions should be improved by cooling channels redesign.

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

References

[1] P. Postawa, J. Koszkul, Influence of processing conditions on changing of shrinkage and mass POM injection molding parts, Proceedings of the 13th Scientific International Conference „Achievements in Mechanical and Materials Engineering" AMME'2005, Gliwice – Wisła, 2005, 531-534.

[2] X.G. Ye, K.S. Lee, J.Y.H. Fuh, Y.F. Zhang, A.Y.C. Nee, Automatic initial design of injection mould, International Journal of Materials and Product Technology 15 (2000) 503-517.

[3] L. Xu, W. Xu, Y. Chen, Plastic injection molding process optimization using software tools, International Journal of Vehicle Design 25 (2001) 53-63.

[4] R. Sikora, E. Bociąga, Characteristic of Tools in Precision Multicavity Injection Moulding, Plastics Processing 81-82 (2001) 161-168 (in Polish).

[5] J.P. Beaumont, R. Nagel, R. Sherman, Successful Injection Molding, Hanser Publishers, Munich, 2002.

[6] J.P Beaumont., Runner and Gating Design Handbook. Tools for Successful Injection Moulding, Hanser, Munich, Cincinatti, 2004.

[7] Beaumont Runner Technologies, http://meltflipper.com.

[8] H.E. Casaldi, T. Michel, Process Window as Effected by Shear Induced Flow Imbalance in Multicavity Moulds, Proceedings of the 59th Annual Technical Conference & Exhibition, ANTEC 2001, Society of Plastics Engineers, 2001, 3112-3119.

[9] P.S. Cook, H. Yu, V. Clinton, V. Kietzmann, F.S. Costa, Prediction of flow imbalance in geometrically balanced feed systems, ANTEC 2005 – Proceedings of the 63rd Annual Technical Conference & Exhibition, Boston, MA, Society of Plastics Engineers, 2005, 526-530.

[10] R. Cooney, D. Neill, L. Pomorski, An Investigation of Part Variation in Multi-Cavity Pressure Control, Proceedings of the 59th Annual Technical Conference & Exhibition, ANTEC 2001, Society of Plastics Engineers, 2001, 3116-3123.

[11] M. Makowski, Runners design for semi-crystalline plastics in injection moulds, Modern Injection Moulds, Design and Exploitation Problems, PLASTECH 2001, Warsaw, 2001, 179-182 (in Polish).

[12] G.Y. Su, H. Yokoi, W.M. Yang, A Study on Filling Imbalance of Plastic Injection Moulding in Multi-cavity Mould with "H" Pattern Runner System, Europe-Africa Meeting of Polymer Processing Society, Athens, 2003, 87-90 (CD-ROM).

[13] E. Bociąga, T. Jaruga, Dynamic mechanical properties of parts from multicavity injection mould, Journal of Achievements in Materials and Manufacturing Engineering 23/2 (2007) 83-86.

[14] T. Jaruga, E. Bociąga, Structure of polypropylene parts from multicavity injection mould, Archives of Materials Science and Engineering 28/7 (2007) 429-432.

[15] E. Bociąga, T. Jaruga, J. Koszkul, Plastic Flow Investigation in Multicavity Injection Mold, Proceedings of the 12th Scientific International Conference „Achievements in Mechanical and Materials Engineering" AMME'2003, Gliwice – Zakopane, 2003, 107-110.

[16] E. Bociąga, T. Jaruga, Microscopic investigations of polymer flow in the runners of 16-cavity injection mold, Polymers 51 (2006) 843-851.

[17] E. Bociąga, T. Jaruga, Visualization of melt flow lines in injection moulding, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 331-334.

[18] E. Bociąga, T. Jaruga, Experimental investigation of polymer flow in injection mould, Archives of Materials Science and Engineering 28/3 (2007) 165-172.