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Structure of gas-assisted injection moulded parts

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ABSTRACT

Purpose: The purpose of this research was evaluation of the structure in the cross-section of gas-assisted injection moulded parts. The parts investigated were stroller handles made from polypropylene.

Design/methodology/approach: Polymer structure was observed in the cross-section using the optical microscope. The microtomed slices cut from the manufactured parts were observed in polarized light. The parts obtained with different injection moulding temperature values were tested.

Findings: was found that spherulites size differs in the cross section. A big gradient of spherulites is observed in the area near the skin while the spherulites contacting the gas channel are of similar size - like those in the part centre.

Research limitations/implications: The investigation is limited to semi-crystalline polymers, like polypropylene. In case of amorphous polymers spherulitic structure does not occur.

Practical implications: The investigation results can contribute to the improvement of the knowledge about gas-assisted injection moulding and can also be helpful in selection of proper injection moulding parameters, in order to obtain good polymer structure in the part.

Originality/value: Gas-assisted injection moulding is a non-conventional manufacturing process. Investigation in this field is not so common like in conventional injection moulding that has much longer history. **Keywords:** Engineering polymers; Gas-assisted injection moulding; Spherulites

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1. Introduction

Gas-assisted injection moulding is a process that allows obtaining hollow parts. The purpose to use it is to manufacture plastic parts of big thickness without sink marks and warpage and, moreover, to shorten the injection moulding cycle, especially by limiting the holding phase of injection moulding cycle.

In a classical case, the process consists of the following steps:

- mould closing
- polymer injecting

- gas injecting
- gas holding and packing

Gas-assisted injection moulding is one of many types of injection moulding processes [1, 2]. The process is shown schematically in Fig. 1. In most cases cavity is not filled totally with polymer. However, there are some solutions that require total filling of the cavity as the first step.

This process consists of several steps that are presented in Fig. 2. In the first step molten polymer is injected into the cavity (so-called *short shot*) - Fig. 2a. During the second step (Fig. 2b),

after delay time, gas is injected to the cavity. In industrial production delay time is very short-just a few seconds [3]. Delay time of gas injection makes creation of solidified outside layer of polymer possible that is called a 'skin'. Skin thickness is dependent on delay time: shorter delay time causes thinner skin formation. Skin thickness depends also on the volume of polymer staying in the cavity.



Fig. 1. Scheme of gas-assisted injection moulding process [based on 2]



Fig. 2. Consecutive steps of gas-assisted injection moulding process, with injecting the gas inside the part: a-d - steps of the process, 1-molten polymer, 2-solidified polymer layer, 3-injection mould, 4-flow front of the polymer, perpendicular flow is marked, 5-channel formed during gas injection, 6-injection mounded part, g-part wall thickness [4]

The gas pressure is gradually increased (Fig. 2c) that prevents breaking polymer layer from the flow front and damage of the product [2, 3]. Gas channel forming starts from the moment of gas injection to the part's interior. The part wall thickness changes during the process. First, the thickness is small; gas under pressure spreads the polymer in the cavity (Fig. 2b). In the next step of the process the polymer flows further, to the cavity walls; the polymer part wall thickness increases (Fig. 2c). The last step is the holding phase-polymer fills up the cavity being under pressure, gas prevents sinks formation from the part's surface and the part's wall reaches the final thickness "g" (Fig. 2d).

The gas used for this process is nitrogen. The advantage of this kind of gas application is purchase or production costs that are relatively low. Gas is injected according to the pressure profile introduced earlier to the controller. Gas under pressure moves to the place, where it meets the lowest resistance-to the flow front of molten polymer, where the lowest polymer pressure occurs. The injected gas makes the molten polymer to move towards the cavity walls and this enables obtaining the parts that are exactly of the cavity shape [1-5].

Gas is injected to the polymer part to obtain better filling of the cavity and the effect of gas injection substitutes for holding pressure phase (Fig. 2d). In conventional injection moulding process this phase is realized by injection of small amount of polymer after finishing the phase of cavity filling. In gas-assisted process, polymer pushing to the cavity walls is obtained by keeping the gas pressure on the optimal level [1-9]. Holding phase is at the same time a cooling phase and this time solidification of the rest of liquid (molten) polymer occurs. Delay time influences skin thickness and, as a consequence of that, the time of cooling phase. Thick skin requires longer time of the cooling phase. Before finishing the process cycle, gas is removed from the part and directed to cleaning, to use it once again. After gas removal the part is ejected from the cavity.

The costs of the process are higher than in conventional process because additional device for gas application and control of this process is required.

The disadvantages of gas-assisted injection moulding are i.e. slow cooling time and flow marks and post-warpage that is caused by hot gas core. These problems can be solved when using modification of this process that is called Reverse Gas Injection Moulding (RGIM) [10].

GAIM process simulations are performed in order to predict the polymer and gas flow in the mould cavity [11]. Different kinds of CAE (Computer-Aided Engineering) software for performing injection moulding process simulation are very useful in this field. It is possible to forecast how the molten polymer will behave during the injection phase and how the gas will be distributed in the part. This kind of software is used for analysis of conventional and the other special injection moulding processes to assess injection moulded parts quality [12] for example, by forecasting some failures that can occur in parts. Simulation programmes have also possibilities to study the cooling process of injection mould that is very important for obtaining parts of good quality [13].

Except for simulation there are some experimental studies on process visualization [14]. It showed the differences between gas-assisted and water-assisted injection moulding process.

The research of processing parameters influence on parts' quality, made and described in some publications. The analyses are taken up to optimise the values of processing parameters in order to obtain parts of large gas channel (void) because of savings in material and to obtain the uniformity of a part wall [15]. A study on GAIM of polystyrene parts [16] showed that gas penetration, residual wall thickness and mechanical properties of parts depend mostly on such processing parameters like shot size and delay time. The gas bubbles formation around gas channel that is a blemish can be reduced by gas holding pressure decrease as well as gas holding time should be increased as long as possible [23].

It is important to obtain good structure in part cross-section. The structure can be influenced by processing parameters [18-19] as well as by polymer flow in mould runners [19-22] or in the cavity. The influence of cooling rate on the formation of oriented crystalline structure was studied in [23]. I was found that in GAIM process shear rate is enhanced by gas penetration. As a consequence, in different shear rate regions, different structure is formed: oriented lamellar structure in the skin, shish-kebab structure in the subskin and common spherulites in the gaschannel region. Cooling rate has big influence on forming the oriented crystalline structure. The morphology of parts manufactured in conventional injection moulding process and in gas-assisted process is different. As it was described in [24] gas penetration in GAIM process enhances formation of oriented structure that is formed in the skin zone, and much less oriented structure is formed in the inner zone-near gas channel. Structure of PE-HD GAIM parts is characteristic of banded spherulites occurring in the inner zone of the part while this kind of spherulites occurs in outer zone in conventional injection moulded parts [25].

Orientation of fibres in GAIM parts is also different than in parts manufactured in conventional injection moulding process. As it was shown in the case of parts made of polyamide filled with glass fibres the fibres located near gas channel wall are oriented disorderly [26].

2. Experimental

The structure of gas-assisted injection moulded polypropylene parts was investigated. The parts are handles of stroller, manufactured in the real production (machine and mould) but - for the purpose of this investigation - with different selection of parameters, according to the design of experiment. In this study structure of parts manufactured with different melt temperature were compared.

2.1. Injection mould

The injection mould for a stroller handle (double cavity) was used for the investigation. The photography of the mould is shown in Fig. 3.

2.2. Processing parameters

The polymer used for investigation was polypropylenepolyethylene copolymer: K593, manufactured by Slovnaft, with polyethylene fraction content of 10-14%.



Fig. 3. Double-cavity injection mould with gas nozzles

The processing parameters went as follow:

- melting temperature: T_m=175°C / 225°C
- injection time: t_{inj}=4 s
- holding pressure: p_H=5 MPa
- holding/cooling time: t_H=41 s
- switchover (delay) time: t_{so}=2 s

The investigation was made with a wider range of the processing parameters, according to the plan of experiment [10]. In this study the influence of most significant parameter on polymer structure in the parts was analyzed.

The injection moulded part is schematically shown in Fig. 4.



Fig. 4. Scheme of the part and the part's cross-section

The point to take the samples for microscopic investigation was shown in Fig. 5. The samples were not taken from the place of gas channel begin but in a certain distance. It was because the gas channel was not sufficiently well-formed by gas nozzles in the mould in many samples. This would make sampling difficult and have negative influence on investigation results.

B



Fig. 5. Places of taking the samples for microscopic investigation

2.3. Tests performed

First observations were done with the use of stereoscopic microscope Nikon SMZ800 on surface of the samples cut from the parts, from the region with the gas core. Then microtomed slices were taken out of the parts in order to investigate the structure of the parts. The microtome used for preparation the slices was Thermo Shandon Finesse Me+. The slices were put between two glasses and observed at Nikon Eclipse E200 microscope in polarized light.

3. Results and discussion

The parts manufactured with different parameters have different size of the gas core. Parts obtained with low melt temperature $(175^{\circ}C)$ have bigger gas channel, of regular size - Fig. 6. Since low temperature molten polymer is of high viscosity, gas diffusion into polymer was difficult during the process and the internal surface of the parts - gas channel surface - is smooth. In case of samples obtained at high melt temperature (225°C) gas diffusion caused pores formation. The gas channel is of smaller size but there are many pores in the area contacting the internal wall of the part - see Fig. 7.

3.1. Observation of structure in gas channel wall area and in the part skin

The size of spherulites formed at gas channel wall and part skin (injection mould wall) were compared. First, the comparison of samples taken from parts manufactured at different melting temperature are given in Fig. 8 and 9.



Gas channel

C

Skin layer

D



Fig. 7. Cross-section of sample obtained with melt temperature $T_m\!\!=\!\!225^\circ\!C$



Fig. 8. Cross-section of sample obtained at the melting temperature $T_m{=}175\,^{\rm o}C$



Fig. 9. Cross-section of sample obtained at the melting temperature $T_m\!\!=\!\!225^\circ C$

In both cases morphology is similar at skin layer - a big gradient of spherulites occurs because of intensive heat exchange between cold mould wall and the polymer. The observations of microtomed samples allowed also for identifying the pores formed during gas diffusion. There are only single, small-size pores in the parts of T_m =175°C. The size of these pores is in the range of 0.2 to 0.4 mm. The pores are placed very close to the gas channel wall in the part. The pores in parts of T_m =225°C are much bigger - 0.5 to 3.0 mm and elongated in the direction perpendicular to gas channel boundary in the cross-section. The reason for that is gas movement towards outer

boundaries of the cross-section due to gas pressure in the inner channel.

The structure in three different areas: skin layer, middle of the sample and layer contacting gas channel is shown in Fig. 10-12 for parts of lower melt temperature ($T_m=175^\circ$ C) and in Fig. 13-15 for parts obtained at higher melting temperature ($T_m=225^\circ$ C). The significant difference between these parts occurs at gas channel. Except for much bigger porosity of part at $T_m=225^\circ$ C, the size of spherulites is much bigger in the layer contacting the gas channel and around pores. It is caused by better conditions for crystallization in polymer of higher temperature.

In parts of $T_m=175^{\circ}$ C there is a big gradient of spherulites in gas core wall area: very small spherulites occur in the layer of thickness approximately 0.3 mm and the next are big spherulites of size 20-40 μ m. The spherulites surrounding the pores are much bigger that at gas core - about 20-30 μ m.

In parts of T_m =225°C the spherulites are bigger because of higher melting temperature. In the middle part and around the pores the size of the spherulites is about 50-80µm and there is no significant difference in size at gas core.



Fig. 10. Structure of polymer from sample obtained at the melting temperature $T_m=175^{\circ}C$ - skin layer area



Fig. 11. Structure of polymer from sample obtained at the melting temperature T_m =175°C - the middle part area



Fig. 12. Structure of polymer from sample obtained at the melting temperature $T_m=175$ °C - gas channel area



Fig. 13. Structure of polymer from sample obtained at the melting temperature $T_m=225$ °C - skin layer area



Fig. 14. Structure of polymer from sample obtained at the melting temperature $T_m=225^{\circ}C$ - the middle part area



Fig. 15. Structure of polymer from sample obtained at the melting temperature $T_m=225^{\circ}C$ - gas channel area

4. Conclusions

Structure of gas-assisted injection moulded parts is highly influenced by gas injection. The spherulites located close to the skin are very small - like in conventional injection moulded parts while these located at gas core can be of different size, depending on polymer melting temperature: well-grown if the melting temperature is high and poorly grown if it is low.

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