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P. PALUTKIEWICZ[1*], P. POSTAWA[1], J. WAWRZYNIAK[1]

THE IMPACT OF SELECTED INJECTION CONDITIONS ON THE PROPERTIES AND STRUCTURE OF MOLDED PARTS MADE OF HDPE WITH CHEMICAL BLOWING AGENT

In this work, the influence of plastic injection molding conditions, mainly plasticizing conditions: plasticizing pressure (back pressure) and decompression (suck-back) after dosing on weight, thickness, mechanical properties and structure of HDPE parts obtained by injection molding with the addition of chemical blowing agent was done. In order to enable the manufacturing of correctly made molded parts under given plasticizing conditions, other parameters (hold time and hold pressure, injection velocity and injection time) were also changed. It was found that making correct molded parts using decompression requires increased hold pressure and hold time. The share of the porous structure in the parts is inversely proportional to the decompression as well as the hold pressure and hold time, while the plasticizing pressure has little effect on thickness, mass, tensile strength and elongation at maximum force, however, it affects the structure of the molded parts to some extent.

Keywords: injection molding, polyethylene, blowing agents, foaming

1. Introduction

The formation of a porous structure in injection molded parts is a complex process depending on the type of polymer, blowing agent and the injection molding conditions and the construction of mold runners and shape of mold cavities. The size and distribution of the pores in the plastic affect the properties of the whole part. In the literature, it can be found a description and results of studies on the impact of basic injection conditions on the foaming process [1,2]. However, there are few results of studies on the impact processing conditions on the obtained porous structure. In this paper, the impact of plasticizing conditions on selected properties and structure of foamed HDPE molded parts was assessed.

In work [3], the effect of the blowing agent content, mold temperature, injection temperature, injection pressure and backpressure on the structure of injection molded parts from LDPE with exothermic blowing agent was examined. It was found, that the percentage of the blowing agent and the injection pressure have the significant impact on the quality of the porous structure. However, mold temperature strong affects the thickness of the solid skin layer. The relationship between mold temperature and the size and density of the pores was negligible. Backpressure influenced the thickness of the solid skin, the pore size and density of the obtained porous structure. Injection temperature did not have a significant effect on the density of the parts.

The effect processing conditions of structure of foamed molded parts was also widely investigated by authors [4]. It was shown, that the weight of the porous parts decreases with increasing injection temperature, the thickness of the solid skin layer increases in proportion to the mold temperature. It was proved, that the size of pores obtained in structure has a decisive influence on the weight of parts.

In works [5] and [6] authors presented the results of the investigation of processing conditions and blowing agent percentage on selected properties of HDPE molded parts. The examinations showed that the mold temperature have the main influence on the properties and surface state of molded parts from solid and foamed HDPE. With the increase of the mold temperature, the weight, density, mechanical properties, and gloss of molded parts increases. The mold temperature also influences significantly the number and size of pores in molded parts. It was found, that the addition of blowing agent in a quantity of 2% is sufficient to obtain parts with favorable mechanical properties and good surface quality. The reduction of the hold time for porous parts does not significantly affect their mechanical properties relative to solid parts.

[1] CZESTOCHOWA UNIVERSITY OF TECHNOLOGY, FACULTY OF MECHANICAL ENGINEERING AND COMPUTER SCIENCE, DEPARTMENT OF TECHNOLOGY AND AUTOMATION, 21 ARMII KRAJOWEJ AV., 42-201 CZESTOCHOWA, POLAND

* Corresponding author: palutkiewicz@ipp.pcz.pl

Thy also examine the influence of mold temperature and blowing agent percentage on the structure and selected properties (weight, mechanical properties, surface state – gloss and color) of molded parts from HDPE. It was shown that the content of blowing agent in polymer influences not only the amount of pores in the part core, but also the thickness of solid skin. The weight of molded parts from HDPE without and with 2% of the blowing agent addition, decreases slightly with an increase in the mold temperature. There is no significant difference in the weight of parts made of HDPE without and with 2% of the blowing agent, obtained at the same mold temperature. For parts from HDPE containing 4% of blowing agent, differences in weight due to different processing conditions were higher. Parts made of HDPE with 4% of the blowing agent, injected at the low mold temperature, had the lowest weight, which can be explained by the occurrence of numerous fine pores in the core. The surface state investigations showed, that with the increase in blowing agent content, the gloss of parts decreased and also caused the bigger change in their color.

The results of the investigations conducted to determine the influence of the type and content of blowing agents on the structure and selected physical and mechanical properties of injection molded parts are presented in work [7]. Thermoplastics polymers (PP, LDPE and PVC) were used in the investigations. In the present investigations, the blowing agents of the endothermic and exothermic character of the decomposition were used. It has been found, that the preferred content of the blowing agent in the processed material is up to 0.8% wt.. With such a blowing agent content, the pore distribution in the plastic is homogeneous and the pores have similar sizes. Molded parts with such a quantity of blowing agent are also characterized by favorable strength properties. Analyzing the results of density measurements, quantitative porosity assessment and optical examination of the porous structure, it was found that the blowing agent leads to a density reduction relative to solid molded parts. The decomposition of the exothermic blowing agent takes place in an uncontrolled manner, even when the heat supply for decomposition is stopped. For this reason, the molded parts produced with this type of blowing agents often have a non-homogeneous porous structure. In the case of porous molded parts produced using a blowing agent with endothermic decomposition characteristics, the release of gas during processing ends when the heat supply is stopped. The obtained porous structure is homogeneous and the pores have a spherical or quasi-spherical shape. The number of pores occurring in certain areas of the cross section increases in a directly proportional manner with increasing the content of foaming agent in the processed polymer.

Paper [8] presents the results of the investigations of the effectiveness of foaming process with using various types of blowing agents, in the process of HDPE injection molding. Six types of blowing agents were used, including four endothermic and two exothermic. The polymers were injected with or without hold pressure. The weight, density, dimensional stability, surface state and structure of molded parts was evaluated. Also, the processability of plasticized HDPE with blowing agent was evaluated on the basis of its flow into the injection mold with spiral cavity. The pore growth process was investigated using the self-designed test stand. The melt flow rate (MFR) of the HDPE with various blowing agents was also determined. The obtained parts were characterized by a good mapping of the shape of the mold cavity. Porous parts, however, have a worse surface condition (gloss, color), than solid parts. The melt flow rate of the plastic with the blowing agents was slightly higher than the MFR of the liquid polymer. There were found significant differences in the structure of the porous molded parts made using different blowing agents.

Many studies investigate the influence of the basic parameters of the injection molding process on the properties of foamed molded parts. In most of them, it has been shown that the type and amount of the dosed blowing agent and the mold temperature have a significant influence on the properties of foamed parts. There are not many studies that describe the influence of plastic plasticization parameters.

2. Effect of plasticizing pressure and decompression

In the plasticizing phase, the homogenized polymer is displaced towards the injection nozzle with simultaneous reverse and rotational movement of the screw. Limiting the rectilinear backward motion of the screw improves homogenization and increases the packing of material on the screw head. The plasticizing pressure (back pressure) is generated by a hydraulic cylinder and prevents the injection screw from returning during the plasticizing phase (Fig. 1) [9]. Its value is regulated by creating pressure (p_r) in the hydraulic cylinder. The plasticizing pressure is therefore the resultant pressure of the screw turning resistance, setting value in the hydraulic cylinder (p_r), and is also dependent on the viscosity of the polymer material. The plasticizing pressure improves the material homogenization process, however, it can cause the material to overheat due to friction [10,11].

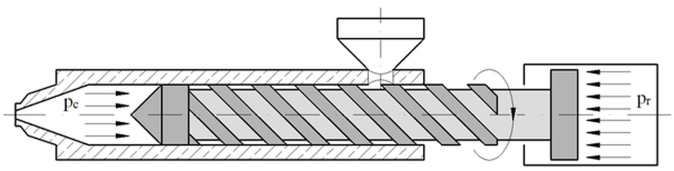

Fig. 1. Principle of creating a plasticizing pressure (back pressure): p_r – setting pressure caused in a hydraulic cylinder (adjustable value), p_c – plasticizing pressure caused in the front of the cylinder during plastic feeding by a rotating screw (real value)

The high value of plasticizing pressure p_c contributes to an increase in the degree of mixing of plastic dyes, but (unfavorably) increases the time of plasticizing cycle and thus the time of the entire injection process, and also contributes to shortening the length of filler fibers and increasing the stress in the plasticizing system of the injection molding machine [11÷13]. In the case of foaming injection molding, a higher value of plasticizing pressure prevents foaming plastic in the plasticizing system of the injection molding machine (in a properly conducted foaming injection process, the expansion of the porous structure should occur as a result of pressure drop in the injection mold cavities) [6]. Therefore, during polymeric material processing, the plasticizing pressure should be increased [14].

The quality of injection molded parts also depends on the use of decompression (suck back) consisting of a small retraction of the screw (without rotation) causing a decrease in the pressure of the material on the face of the screw or injection piston (Fig. 2). Decompression can be used before or after plasticizing depending on the design of the mold and nozzle. In the case of cold-channel molds and open nozzles, decompression is used after plasticizing, while in the case of hot channels, decompression is used before and after plasticizing. Decompression after dosing prevents leakage of plastic from the open nozzle when moving the plasticizing system away from the mold or from hot channels when opening the mold [11,15]. The amount of decompression depends on the material used and the additives used, e.g. blowing agents. Too high a decompression value may result in the introduction of ambient air into the plasticized material in the plasticizing system of the injection molding machine, and thus it may cause defects in the molded parts [12,15,16].

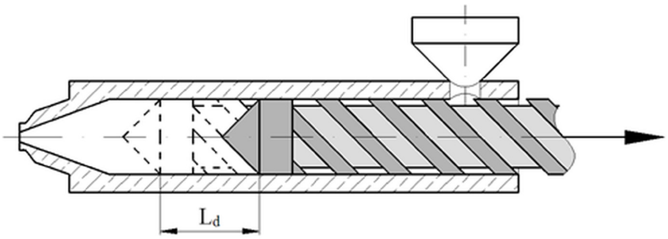

Fig. 2. Retracting the screw in the decompression phase after dosing the polymer material L_d

The important parameter that impact on injection molding process is the cushion. Cushion is the material remaining in the barrel, in front of the screw, after the mold filling and pack stages of the injection process is called the cushion. Having a cushion ensures that the screw does not bottom out against the front of the barrel, thereby preventing control of packing. Cushion is critical for most parts to assure they can be properly packed out [17]. A pressure loss can result if the cushion is too high, and the parts will not mold consistently [18].

3. Experimental investigations

The main aim of this work was to assess the impact of plasticizing conditions: plasticizing pressure and decompression after dosing on the weight, thickness, mechanical properties and structure of foamed high-density polyethylene injection molded parts. In order to obtain correctly made molded parts, without sink marks and with good surface quality, it was also necessary to change the remaining injection parameters: hold pressure, hold time and injection velocity.

The Hostalen GC 7260 (Basell Polyolefins) HDPE was used in investigations. Its properties were the following: 74°C Vicat softening temperature (method B50: 50°C/h; 50 N), and 8 g/10 min melt flow rate (MFR), determined at the temperature 190°C and 2.16 kg load. The porous structure of molded parts was obtained by addition of 3% wt. of Hostatron P 1941 (Clariant) endothermic chemical blowing agent (in a form of granules). Plastic granules were mixed with the blowing agent before the injection molding process.

Specimens, in the shape of tensile bars of 4 mm thickness, were molded according to PN-EN ISO 527-2:1998 standard, using two-cavity mold mounted on KraussMaffei KM65-160 C4 injection molding machine (with open nozzle). The injection molding conditions were as follows:

– injection temperature 220°C,
– cooling time 36 s,
– mold temperature 20°C.

Other variable process parameters are presented in Table 1.

TABLE 1

Variable parameters of the injection molding process

Variable parameter	Numbers of series			
	I	II	III	IV
Hold pressure, MPa	20	60	60	20
Hold time, s	1	5	5	1
Injection velocity, mm/s	92	113	113	92
Injection time, s	0.85	1	1	0.85
Plasticizing pressure, MPa	36	36	10	10
Decompression, cm^3	0	42	42	0
Total cycle time, s	37,85	42	42	37,85

Due to the different values of injection time and hold time, the total cycle time of manufacturing of moldied parts was variable. The view of the obtained part is shown in the Fig. 3.

Fig. 3. The view of obtained molded part

4. Results and discussion

4.1. Molded parts thickness

The thickness of molded parts was measured in the middle of molded parts using a digital micrometer with an accuracy of ±0.01 mm. Height of the mold cavity was 4.1 mm. The results of measurements of molded parts thickness are shown in Fig. 4.

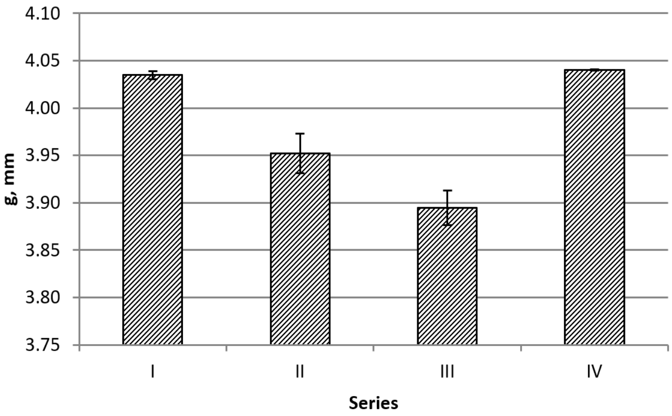

Fig. 4. The thickness of HDPE parts obtained at different injection conditions

The thickness of molded parts made of HDPE obtained without decompression after dosing (series I and IV) is the largest and does not depend on the value of the plasticizing pressure. In contrast, parts made when using decompression (42 cm^3), (series II and III) have a thickness of about 4% smaller compared to the thickness of parts from other series. This may indicate the presence of an unfavorable phenomenon of foaming in the plasticizing system during high decompression after dosing and of partial degradation of the blowing agent as a result of long heating of the plastic with the blowing agent, as well as the limitation of porosity in the mold cavity due to increased hold pressure and hold time.

4.2. Molded Parts Weight

The weight of the molded parts from both mold cavities was determined and the average value was calculated. Standard deviations of all measurements are given in figures. For all measurements 10 samples were used. The Sartorius CP225 balance with close measurement space was used and the weight of parts was determined with ±0.1 mg accuracy. The results of the molded parts weight was presented in Fig. 5.

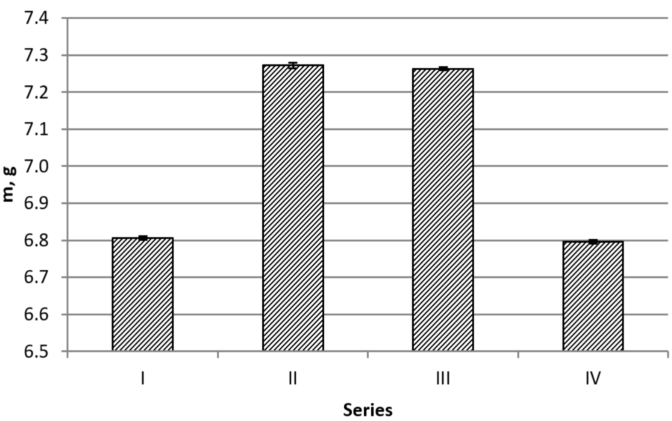

Fig. 5. The weight of HDPE parts obtained at different injection conditions

It can be concluded from Fig. 5 that molded parts produced without decompression after dispensing and reduced pressure and clamping time (series I and IV) have a reduced weight compared to moldings from series II and III. This may indicate that these parts (series I and IV) are characterized by a greater proportion of the porous structure in the mass of the material than those from series II and III. In addition, it can be seen that the plasticizing pressure has a negligible effect on the mass of the material.

4.3. Mechanical properties

In tensile tests the tensile strength (σ_m) and the elongation at maximum force (ε_m) was determined. Examinations were carried out using Hegewald & Peschke Frame Desk 20 machine. The tension velocity was 50 mm/min. The measurement results are presented in Fig. 6 and 7.

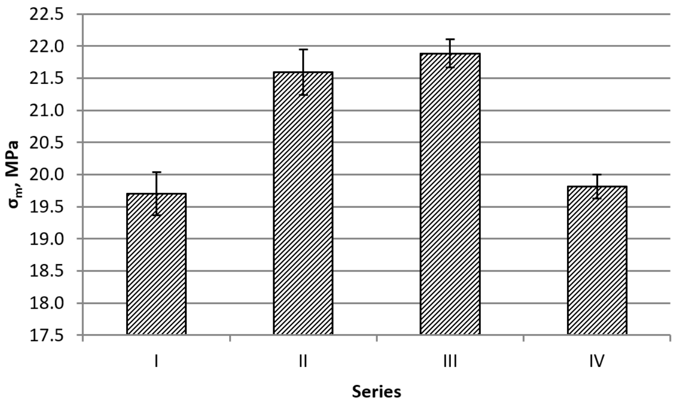

Fig. 6. The tensile strength of HDPE parts obtained at different injection conditions

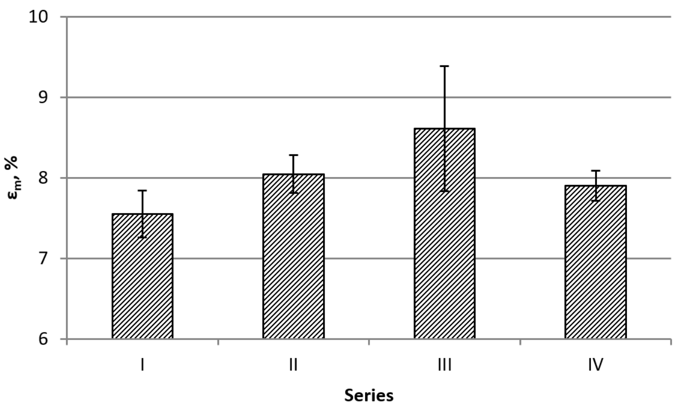

Fig. 7. The elongation at maximum force of HDPE parts obtained at different injection conditions

From Fig. 6 it can be seen that the molded parts made with the parameters of Series II and III have a tensile strength by about 2 MPa higher compared to the other parts (Series I and IV). This may be due to a smaller amount of porous structure due to the occurrence of an unfavorable phenomenon of porosity in the plasticizing system of the injection molding machine, as a result of increased decompression. Higher tensile strength values of these molded parts are also associated with increased hold pressure and hold time. It can also be seen that in the case of increased plasticizing pressure, the parts have lower tensile strength.

It can be seen from Fig. 7 that the change of parameters such as decompression and plasticizing pressure has a small effect on the elongation of the parts at maximum force, its average values vary in the range from 7.5 to 8.5%.

4.4. Structure investigations

The structure of foam molded parts was examined using the Nikon Eclipse E200 microscope. Observations were carried out in the polarized light. Preparations used for the observation were in the form of cuttings of 25 microns in thickness, and were cut from the middle area of the tensile bars, perpendicularly to the polymer flow direction. The results of microscopic observations are presented in Fig. 8.

In molded parts made of HDPE with the addition of 3% blowing agent obtained without decompression after dosing and low values of hold pressure and hold time (series I and IV), the pores are more numerous, have larger sizes and irregular shape, which indicates more intense porosity and possible joining pores with each other, especially when using low plasticizing pressure (series IV). In the case of parts obtained in series IV, the pores appear closer to the skin than in parts made in other series. This may be evidence of intensive plastic porosity in conditions of low plasticizing pressure, and intensive growth of pores in the mold cavity.

In molded parts obtained when using decompression and higher hold pressure and hold time values (series II and III), the pores are smaller and few with a more regular spherical shape than in the case of parts from series I and IV. This may indicate the occurrence of an unfavorable phenomenon of material foaming already in the plasticizing system as a result of decompression after dosing and less intense foaming in the mold due to increased hold pressure and hold time. At the same time, these parts are characterized by a thick, solid skin.

At lower plasticizing pressure (series III), few, small pores of regular shape are obtained, distributed unevenly in the parts core. Such distribution of pores in the parts may indicate the occurrence of the phenomenon of porosity already in the cylinder of the plasticizing system, which is favored by the low value of the plasticizing pressure.

5. Conclusions

The production of high quality molded parts using decompression after dosing requires increased pressure and clamping time. Decompression can cause the blowing agent to decompose and start the foaming process already in the plasticizing system, which adversely affects the structure and properties of porous molded parts. Changing the plasticizing conditions also affects the total injection cycle time.

The porous structure share in the parts depends on decompression value after dispensing as well as hold pressure and hold time.

The plasticizing pressure has a small effect on the thickness, weight, tensile strength and elongation at maximum force,

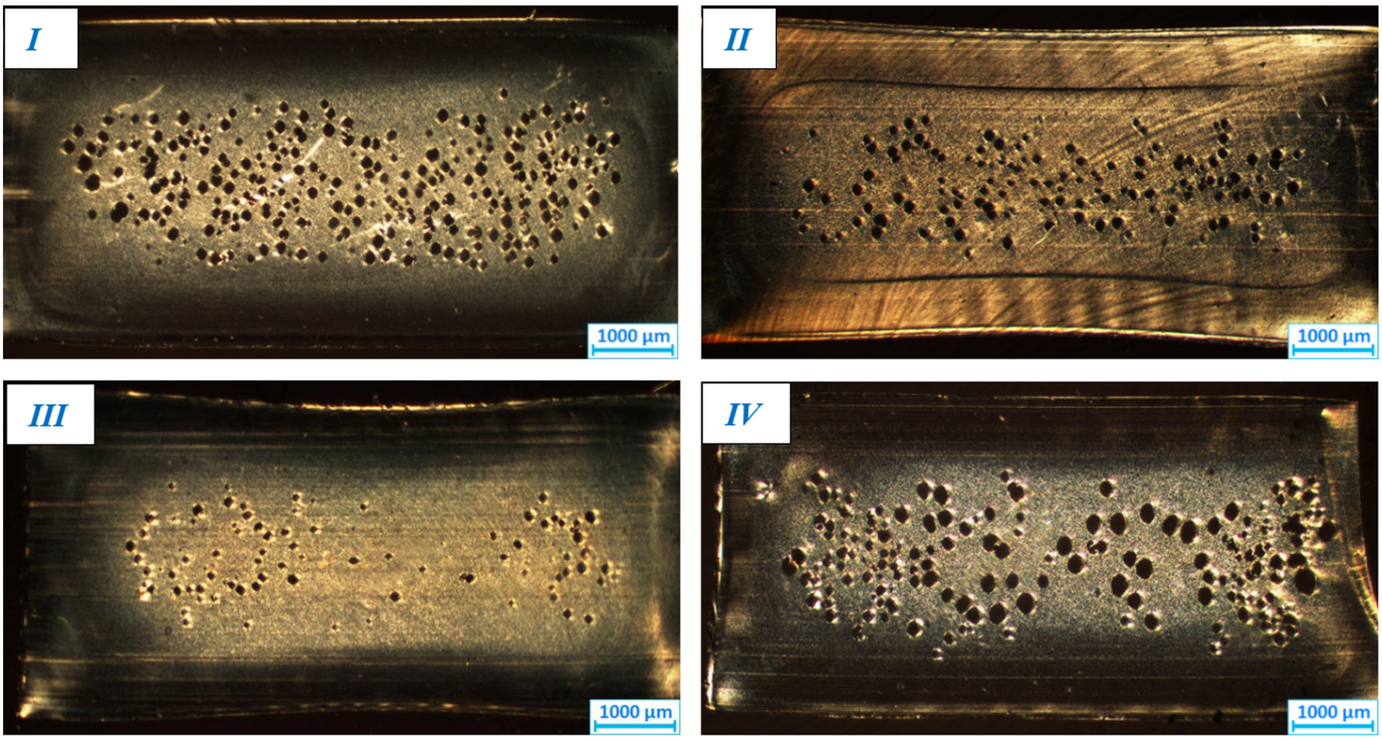

Fig. 8. The morphology of HDPE parts obtained at different injection molding conditions (series I-IV), part height = 4 mm

however, it affects the structure of the molded parts. The pores in parts from series I and II, in which high plasticizing pressure was used, are characterized by evenly distributed pores in the core. In the case of low plasticizing pressure (series III and IV), the pores are smaller, less numerous and distributed unevenness in the cross-section of the part.

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