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Research Article

EFFECTIVENESS OF CELLULAR INJECTION MOLDING PROCESS

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ABSTRACT

In a study of cellular injection, molding process uses polyvinylchloride PVC. Polymers modified with introducing blowing agents into them in the Laboratory of the Department of Technologies and Materiase of Technical University of Kosice. For technological reasons, blowing agents have a form of granules. In the experiment, the content of the blowing agent (0–2,0% by mass) fed into the processed polymer was adopted as a variable factor.

In the studies presented in the article, the chemical blowing agents occurring in the granulated form with a diameter of 1.2 to 1.4 mm were used. The view of the technological line for cellular injection molding and injection mold cavity with injection moldings are shown in figure 1.

The results of the determination of selected properties of injection molded parts for various polymeric materials, obtained with different content of blowing agents, are shown in Figures 4–7. Microscopic examination of cross-sectional structure of the moldings were obtained using the author's position image analysis of porous structure. Based on analysis of photographs taken (Figures 7–9) it was found that the coating containing 1.0% of blowing agents is a clearly visible solid outer layer and uniform distribution of pores and their sizes are similar.

Keywords: thermoplastics polymers, cellular injection molding process, blowing agents, physical properties.

INTRODUCTION

Cellular structure is obtained by insertion of a blowing agent (porophor) in a form of an inert gas, low-boiling liquid or a solid body into the input plastic which, if in liquid or solid state, transforms into gas under determined conditions of the injection molding process. Inert gases and low-boiling liquids are introduced under pressure by means of special dispensing devices, directly into the feeding zone of the plasticizing system [1, 2, 3, 4]]. By contrast, some liquids and solid bodies, such as pigments, are mixed with polymer plastics in a typical way, i.e. prior to their delivery to the injection molding machine dispenser, or they are introduced into the plastic already during the extrusion process. If the process of gas emission is started in the proper temperature, numerous microspheres, which had been generated, dissolve in the ambient plastic material due to the operation of pressure and surface expansion.

Cellular plastic in a liquid form is still not a stable system because as a result of interfacial tension at the plastic – gas contact point, and as a result of diffusion, the number of cells in the plastic is reduced, whereas their dimensions enlarge, what comprises an undesirable effect. The obtained cells keep enlarging until gas pressure and interfacial tension are balanced. Favourable small-cell structure can be maintained in the plastic product by its immediate cooling and solidification. During the injection molding process, blowing agents are exposed to exactly the same conditions as the processed plastic, compression, homogenizing treatment and carrying already before gas emission [2, 3, 6].

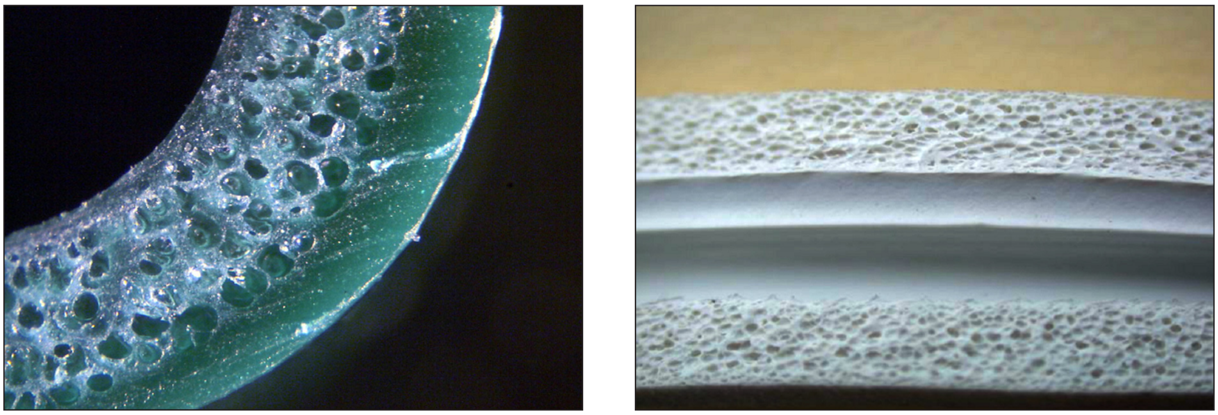

Fig. 1. Cross section of porous structure of polymer products made from the examined polymers

Cellular of thermoplastic materials may be conducted with the use of chemical blowing agents (to maintain low cost of technical equipment and machines used in processing) and physical blowing liquids (gases), to obtain high degree of porosity.

By contracts, chemical blowing agents are added to the granulated polymer as solids (powder, granulated product) fed to the plasticizing system, most often by means of gravimetric or volumetric dispensers. Plastic mixed with the blowing agent is then processed in the plasticizing system and shaped with a traditional tool (injection mould, extruder head etc.). As it is the case with physical blowing agents, gas dissolved in the polymer is obtained [7, 8, 9, 10].

The type and volume of the added blowing agents affects final form of the cellular plastic and determines cellular method. Proper feeding system is the basic condition of effectiveness. Blowing agents should be dissolved in a polymer.

The obtained product may have a fully solid or cellular structure, or it may be cellular in its entirety, or it can have the cellular topcoat and solid surface [5, 7, 12, 13]. Proper distribution of temperature in the plasticizing system of the injection molding machine is required to obtain favorable cellular structure in the process. Temperature in the first, second and alternatively third functional zone of the plasticizing system should be lower than the initial decomposition temperature of the blowing agent. Only in the fourth zone of the plasticizing system, temperature should be higher than decomposition temperature of the blowing agent. Cooling of the cellular product (scope and intensity) determines creation of the cellular structure of the product. Insufficient cooling may lead to the emergence of a non-uniform cellular structure [2, 6, 7, 13, 14].

EXPERIMENTAL PROCEDURE

The polymer used in the experiments was poly(vinyl) chloride PVC, marketed under the trade name ALFAVINYL - GFM/4-31-TR, with a density of 1230 kg/m^3 and tensile stress at yield of 21 MPa, according to the data provided by the manufacturer. In the experiments, two types of chemical blowing agents were used: Hostatron P1941, Hydrocerol 530, both manufactured by Clariant Masterbatches GmbH, ADCOL-blow UP-0X-B-X11020 manufactured by Clariant and Expancel 950MB120 manufactured by AkzoNobel.

Based on the adopted research program, the polymeric material for cellular injection molding was modifed in such a way that the blowing agents were fed in during the mechanical mixing process. The blowing agents used in the cellular injection molding process were fed into the polymers being processed in the following quantities: 0,2%, 0,4% and 2,0% by mass (w/w). In order to obtain high process efficiency for the above blowing agents, the processing temperature range was 170–190 °C.

The test stand consist of a screw injection molding machine, Demag 3-25t, equipped with an injection mold, as shown in Figure 1a. The machine has a single-screw plasticizing system, with a screw diameter of 30 mm. To the moveable table of the machine a moveable subassembly of the injection mold (Figure 1b) is mounted, in which two mold cavities are located. The mold cavity has the shape and dimensions of a tensile specimen for static tension tests, the so–called specimen type II [15].

The mold cavity dimensions are as follows: length 150 mm, width from 10 to 20 mm, thick-

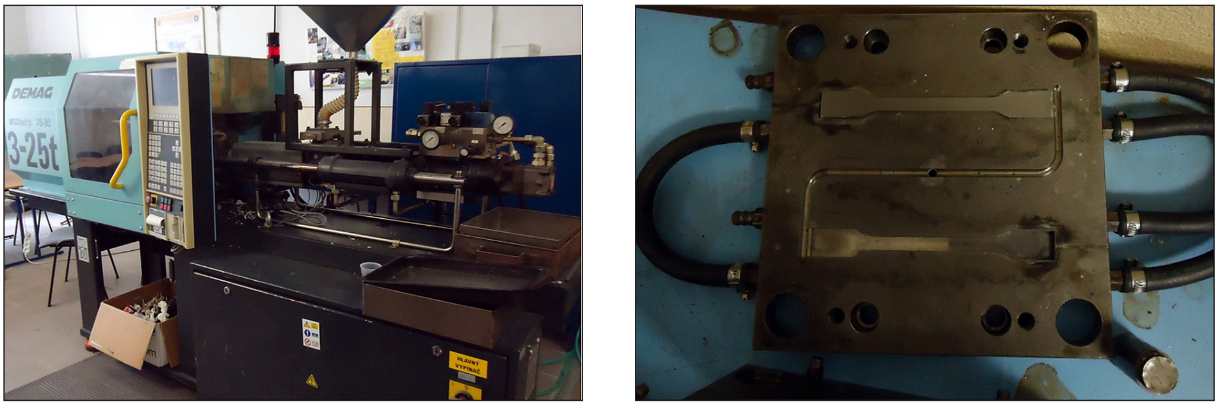

Fig. 2. Test stand used in the experiments: a) injection molding machine Demag 3-25t, b) injection mold unit and molded specimens

ness 4 mm. Directly in the mold cavities there are point ejector pins mounted, with a diameter of 6mm. In the fixed subassembly of the mold, there are flow system channels supplying the polymeric material to the mold cavities; the channels have a direct contact with an injection nozzle of the plasticizing system.

The following parameters of the cellular injection holding process were adopted: injection and clamping time – 2 seconds; molded piece cooling time – 30 s; injection pressure in the hydraulic system – 10 MPa. In the experiments, the temperatures of the investigated PVC polymers were set in specific heating zones of the plasticizing system in the following way: in zone I – 160 °C, in zone II – 170 °C, III – 180 °C, IV – 190 °C.

The applied shape and dimensions of the specimens complied with the relevant norm. The specimen thickness corresponded to the injection molded part thickness and it was measured and registered each time together with the width of the measuring length right before the tests.

The porous products were examined in terms of their selected physical, mechanical and functional properties in accordance with appropriate international norms. Also, tests of tensile strength, hardness, and porous structure were made. The applied shape and dimensions of the specimens complied with the relevant norm. The specimen thickness corresponded to the injection molded part thickness and it was measured and registered each time together with the width of the measuring length, right before the tests.

Strength properties of the injection molded parts under static tension were determined using a testing machine manufactured by TIRA test 2300. The machine was equipped with 10 kN screw wedge chucks together with the accessories. The measurements were done at a tensile speed of 0.83 mm/s (50 mm/min) and under the measuring load range 0–500 N. The hardness tests by Shore's method were conducted using an Affri-manufactured hardness tester, type ART13 – Shore's method D. Such choice was due to the

Fig. 3. Porous PVC injection molded parts with an ingot and a fragment of the molded part with a visible porous structure

employed method for determining hardness of solid polymers [16].

The investigation and analysis of the porous structure of the produced injection molded parts were conducted using authors' stand for porous structure image analysis. Porous structure image analysis is used to determine geometric characteristics of pores, based on the images of porous structure taken. The images are taken using a metallographic microscope, optical camera with an electronic amplifying system and then analyzed in a computer stand equipped with special graphics software.

RESULTS AND DISCUSSION

As a result of the process, the degree of porosity of the obtained porous products ranged from 0% to 45%. The value of the degree of porosity is defined by the percentage of cellular surface in relation to the total tested surface . In density testing of the cellular PVC coat samples, the pycnometrical method was applied.

The results of determining selected strength properties of the injection molded parts, obtained at different contents of the blowing agent in the processed polymers, are shown in Figures 4–5. It has been observed that increasing the blowing agent content in the product decreases the value of tension at break, in a non-linear manner in the whole content range of the blowing agent in the polymer. The distribution of the curves demonstrates that at high content of the blowing agent (over 0.4%) in the polymer, the intensity of the decrease in tensile strength is lower, irrespective of the type of the processed polymer and the type of the blowing agent used. The results of the tensile strength tests, of the specimens made from the polymers modified by the blowing agents correspond to the results of the conducted hardness tests. The injection molded parts made from porous polymers have decreased mechanical properties, strength properties included.

Significant differences in mechanical strength of the porous injection molded parts can be observed. For example, blowing agent P 1941, with the endothermic decomposition characteristics, dosed in the range from 0 to 2.0% causes a decrease in tensile strength by 25–30% on average in the case of PVC (Figures 4, 5).

The results of hardness of the injection molded parts are graphically represented in figure 6. The type of a blowing agent used, be it with the endothermic or exothermic decomposition characteristics, has no effect on the surface hardness of the injection molded parts. The changes in hardness illustrated in the figures predominantly depend on the type and properties of the polymeric materials used in the cellular injection molding process. It has been observed that increasing the blowing agent content in the product decreases the value of hardness, in a non-linear manner in the whole content range of the blowing agent in the polymer. The pore structure becomes finer and finer, the number of pores increases, while their size is decreased. Moreover, such a large content of blowing agent is economically ineffective.

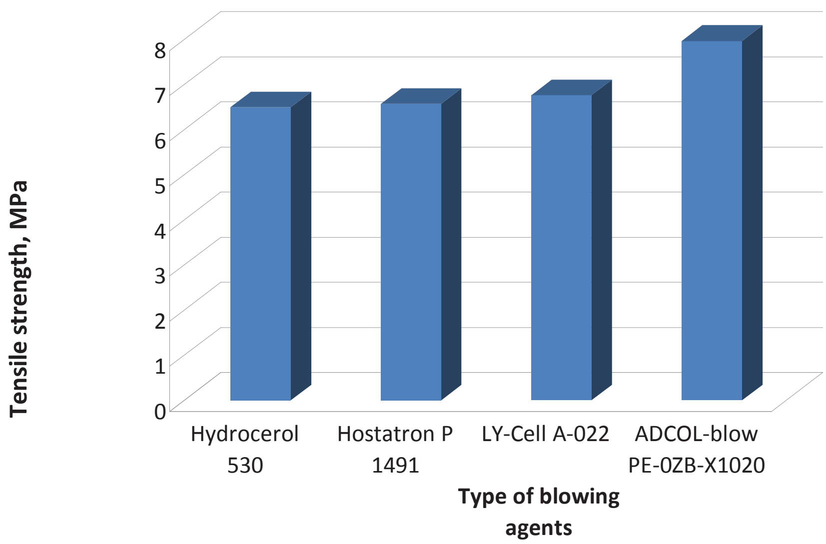

Fig. 4. Dependence of tensile strength of the injection molded parts made from the injected polymers on the content of blowing agents 0,4 % by mass

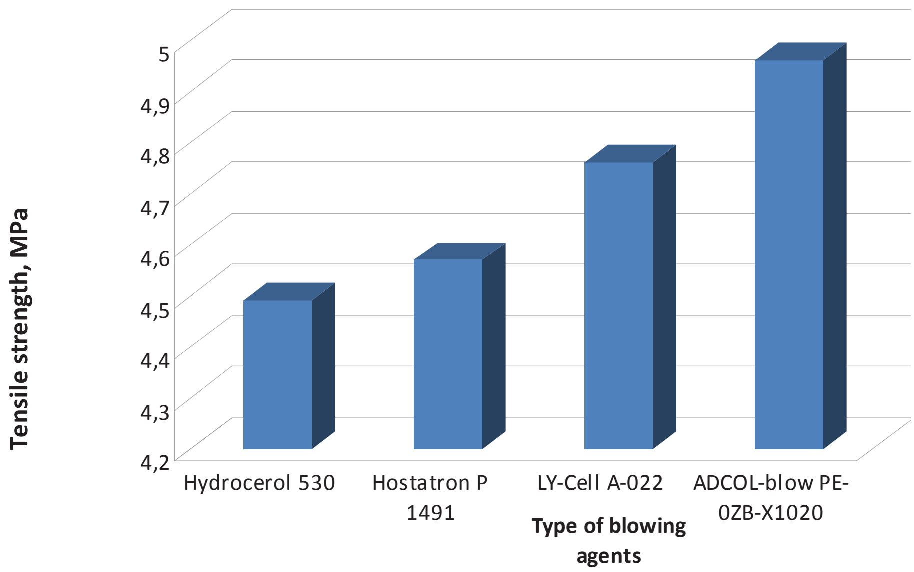

Fig. 5. Dependence of tensile strength of the injection molded parts made from the injected polymers on the content of blowing agents (2,0 % by mass)

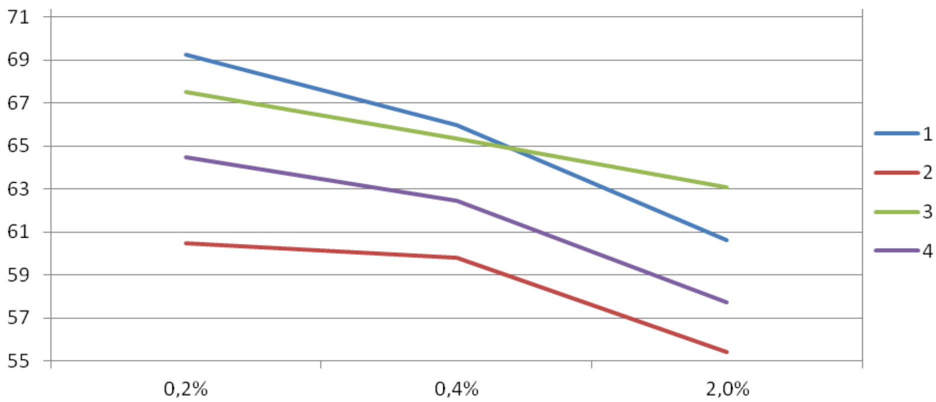

Fig. 6. Dependence of hardness of injection molded parts examined with Shore's method on the content of blowing agents, 1 – Hydrocerol 530, 2 – Hostatron P 1491, 3 – LY-Cell A-022, 4 – ADCOL-blow PE – 0ZBX1020

A discernible effect of the blowing agent used, its type and effect characteristics on the obtained morphology of porous molded pieces have been observed. Based on the analysis of the photographs taken, it has been found that the injection molded parts with 0.2% content of the blowing agent (Figure 7) have a clearly visible solid outer layer and their pore distribution is non-uniform to the greatest extent.

The change in the number of pores and their surface quantity in the cross section of the molded parts can also depend on cooling intensity. Fast cooling hampers the occurrence and growth of pores, especially of those located closer to the surface layer. The outer layer of the molded part undergoes direct and fastest cooling in the mold, which is why the number, size and surface quantity of the micro pores produced in this region are lower compared to the regions located closer to the core of the molded parts.

CONCLUSIONS

The blowing agents used in the cellular injection molding process give a possibility of creating products with new, modified properties, without causing important changes. The change in these properties offers new possibilities of applying this kind of products with simultaneous reduction in their production costs.

In the molded parts with 0.4% content of the blowing agent, the pore distribution is more uniform, and the visible pores are of similar sizes In the case of the molded parts with 2,0% content of the blowing agent (Figures 7–9), there is a sub-

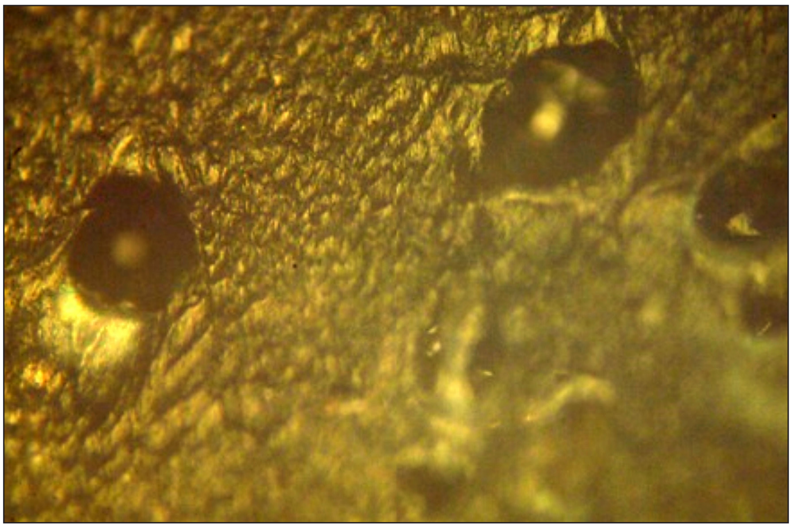

Fig. 7. Microscopic image of the cross section of the made of cellular tape polymer of the amount of the blowing agent (LY-Cell A-022) 0,2% mass, magnify 50×

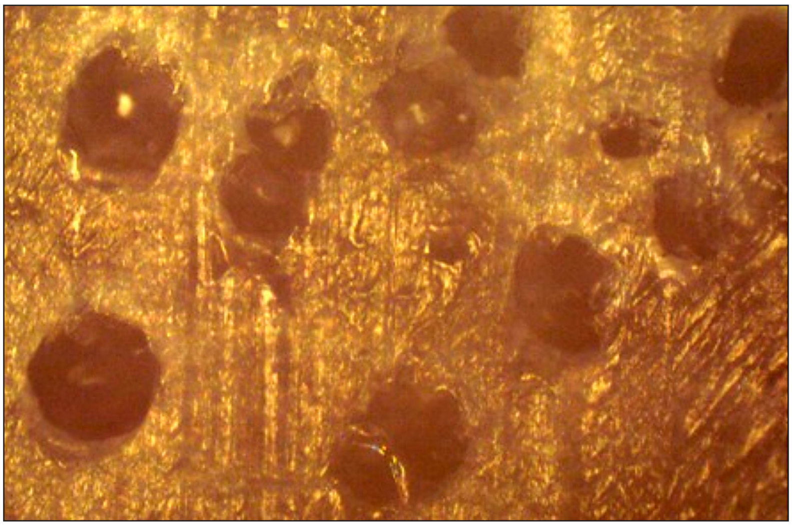

Fig. 8. Microscopic image of the cross section of the made of cellular tape polymer of the amount of the blowing agent (Hydrocerol 530) 0,4% mass, magnify 50×

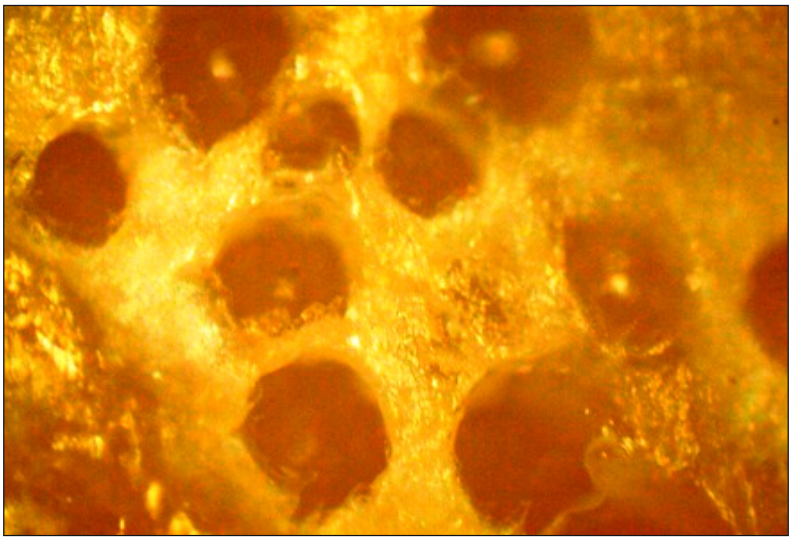

Fig. 9. Microscopic image of the cross section of the made of cellular tape polymer of the amount of the blowing agent (ADCOL-blow PE-0ZBX1020) 2,0% mass, magnify 50×

stantial concentration of pores of various sizes which, in extreme cases, can cause a discontinuity in the solid outer layer. For specific contents of the blowing agent in the polymeric material, the examined pore diameter increases, as the measuring capacity changes towards the product core. The smallest pore diameter was observed for the solid outer layer. The closer to the core the solid outer layer is, the more the pore size increases. The increase was most intensive at the lowest content of the blowing agent in the polymer being processed. As the dose of the blowing agent increases, the increase in the pore diameter for particular contents of this agent was smaller and smaller.

In the case of the porous parts produced using the blowing agents with the endothermic decomposition characteristics, the gas release in the course of processing comes to an end once the energy supply is stopped. The obtained porous structure is uniform; the pores have a spherical or quasi spherical shape. The pores have similar sizes, irrespective of their location in the product.

The porous structure is an advantage of injection molded parts produced in the cellular injection molding process, as it results in a decreased amount of the polymeric material needed in their production. Owing to the use of chemical blowing agents, porous parts have, among others, lower weight, enhanced damping properties, and lower processing shrinkage. Changing the injection molded part structure from solid to porous by using appropriate types and content of the blowing agents, brings numerous economical benefits without simultaneous decreasing the properties of such parts to values below expectations.

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REFERENCES

1. Kelvin T. Okamoto.: Microcellular processing. Hanser Publishers, Munich, Germany 2003.
2. Bociąga E., Palutkiewic P.: Wpływ zawartości poroforu i warunków wtryskiwania na wybrane właściwości i stan powierzchni wyprasek z polipropylenu. Polimery, 1, 2012, 38-42.
3. Dulebová Ľ., Greškovič F.: Influence of regrind on properties of plastics processing by injection moulding. Materials Engineering - Materiálové inžinierstvo,18, 44, 2011.
4. Greškovič F., Dulebová Ľ., Varga J.: Technológie spracovania plastov. Vstrekovanie. Plastics Processing. Technologies. Injection Moulding, SjF TU v Košiciach, Košice 2010.
5. Matuana LM, Park CB, Balatinecz JJ.: Structures and mechanical properties of microcellular foamed polyvinyl chloride. Cellular polymers, 17, 1998, 1-16.
6. Bledzki K., Kirschling H., Steinbichler G., Egger P.: Polycarbonate microfoams with a smooth surface and higher notched impact strength. Journal of Cellular Plastics, 40, 2004, 489–496.
7. Garbacz T.: Properties of triple-layered PVC coatings synthesized in the micropore coextrusion method. Polimery, 56, 2011, 129-134.
8. Моравський В. С., Красінський В. В., Сікора Я., Кшижак А., Суберляк О. В.: Хімічна промисловість України, 6, 46, 2011.
9. Guo M.C., Heuzey M.C., Carreau P.J.: Cell structure and dynamic properties of injection molded polypropylene foams. Polymer Engineering and Science, 47, 2007, 1070–1081.
10. Klepka T., Dębski H., Rydarowski H.: Characteristic of high-density polyethylene and its properties simulation with use of finite element method. Polimery, 54, 2009, 668-673.
11. Zhou Q., Chuan-Bo C.: Exo-endothermic blowing agent and its blowing behavior. Journal of Cellular Plastics, 41, 2005, 225-234.
12. Sikora J.W.: Screw extrusion. In: Sabu T., Yang W. Advances in polymer processing. From macro to nanoscales. Woodhead Publishing Limited. Oxford-Cambridge-New Delhi, United Kingdom 2009.
13. Tor-Świątek A., Samujło B.: Use of thermovision research to analyze the thermal stability of microcellular extrusion process of poly(vinyl chloride). Maintenance and Reliability, 15, 2013, 58-61.
14. Garbacz T., Tor A: Effect of porophor content on the useful properties of external coatings of cables obtained by foaming extrusion. Polimery, 52, 2007, 286-293.
15. PN-EN ISO 527-1 (2010): Plastics. Determination of tensile properties.
16. PN-EN ISO 868 (2003): Plastics and ebonite. Determination of indentation hardness by means of a durometer (Shore hardness).